UNIVERSITY OF BIRMINGHAM

Science and Technology Facilities Council

Boulby Underground Laboratory

Ultra-pure electroforming at Boulby deep underground laboratory

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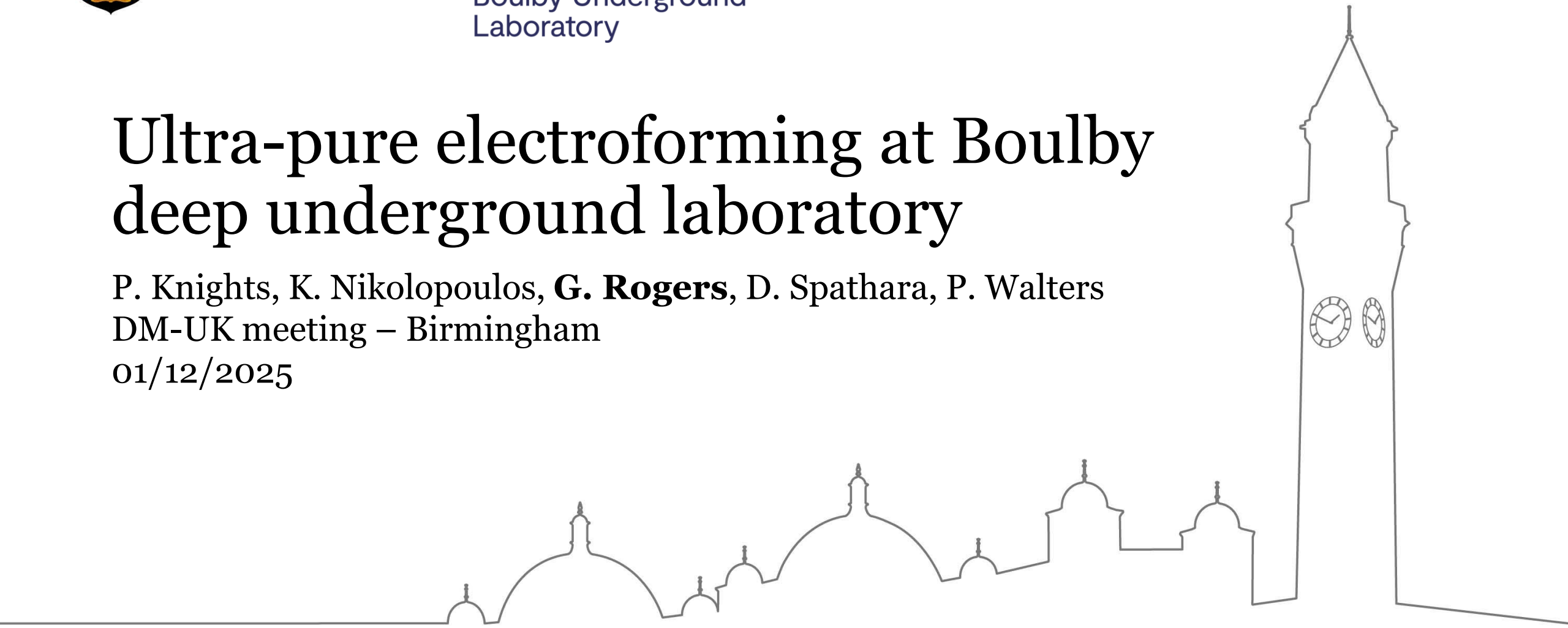
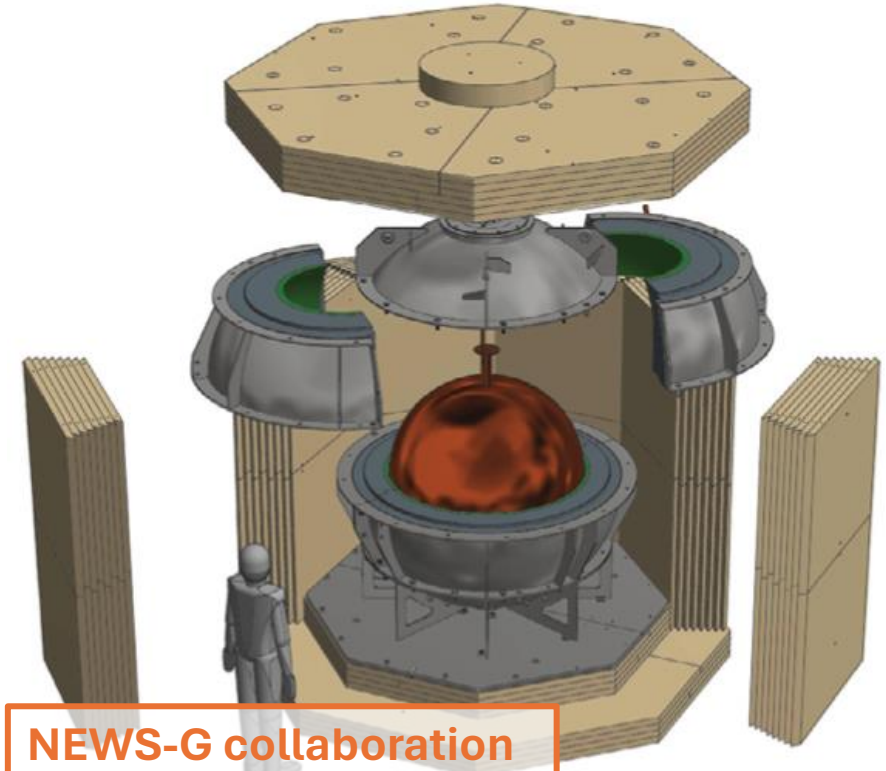
DM-UK meeting – Birmingham

01/12/2025

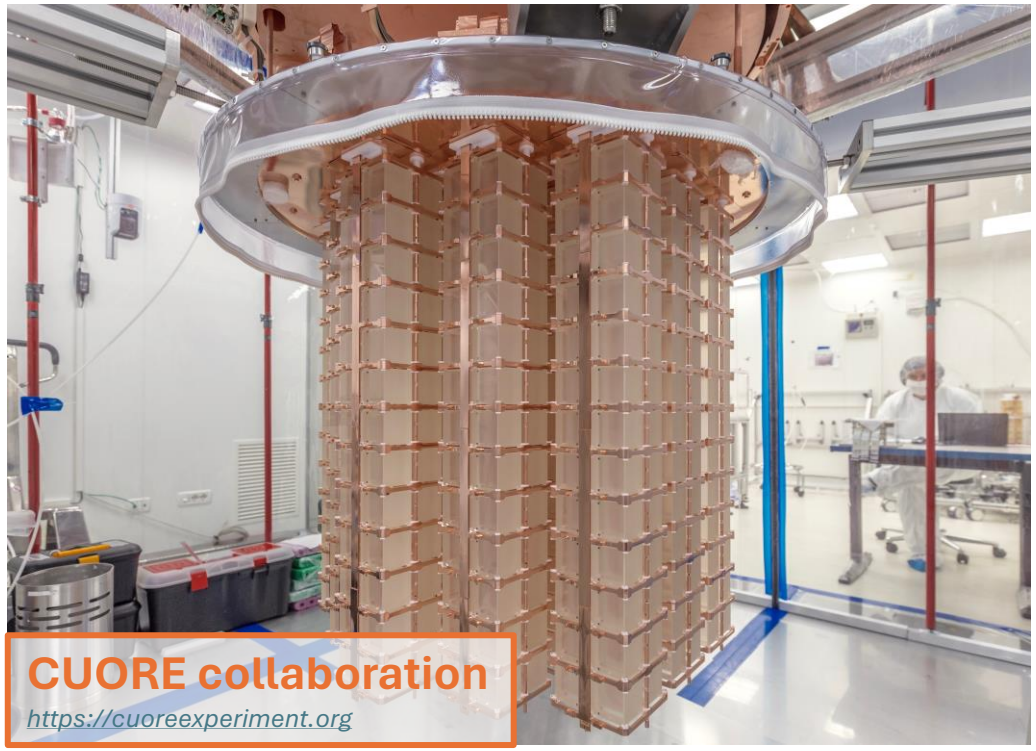


Copper as a detector material

- Copper is a common detector material for rare event searches
  - No long-lived radio-isotopes – longest ^{67}Cu: $t_{1/2}$ = 62 h
  - Commercially available at high-purity available
  - Good mechanical and electrical properties
  - **Favorable electrochemical properties** – more on this later!



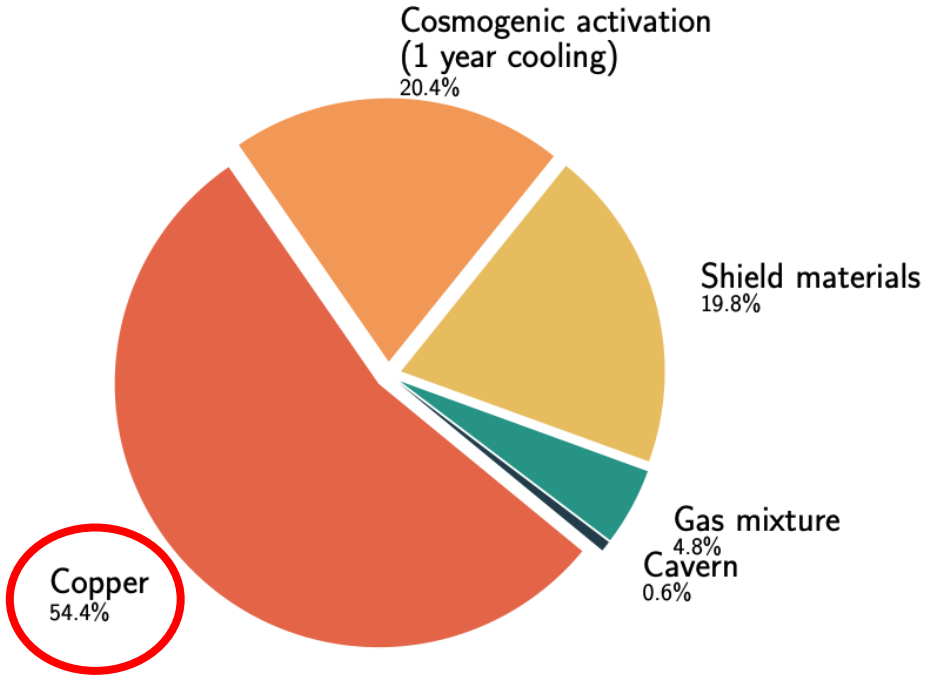
NEWS-G collaboration
https://www.snolab.ca/experiment/news-g/



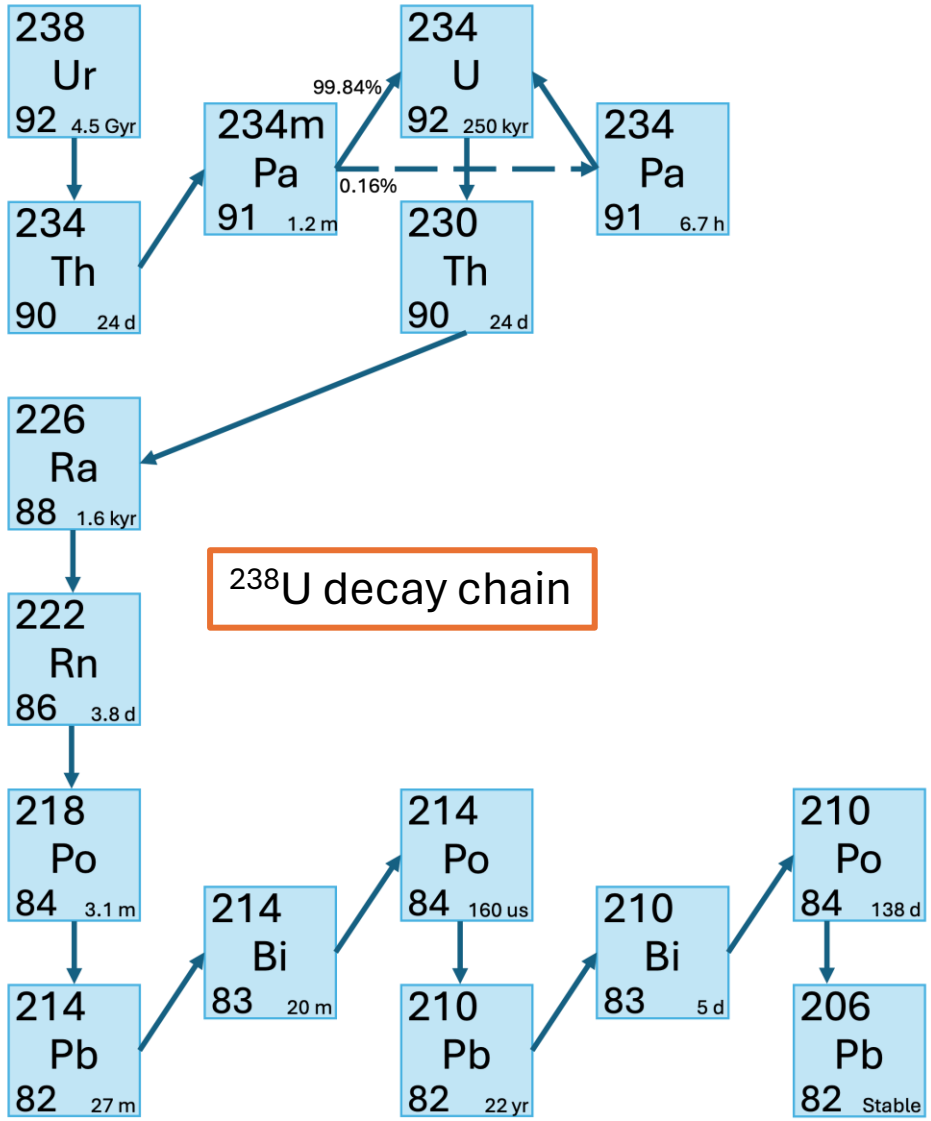
CUORE collaboration
https://cuoreexperiment.org

Copper background

- Copper can still represent an important background
- Commercial copper contaminated - ^{238}U and ^{232}Th decay chains:
  - Natural ore contamination
  - Implanted during manufacture and handling
  - Cosmogenic activation - $^{63}Cu(n,\alpha)^{60}Co$ $t_{1/2}$ = 5.27 yr



Simulated backgrounds for NEWS-G's current detector



^{238}U decay chain

Electrodeposition

- Deposit ions onto a cathode by applying a voltage
- Governed by oxidation and reduction reactions
- Deposited mass proportional to current

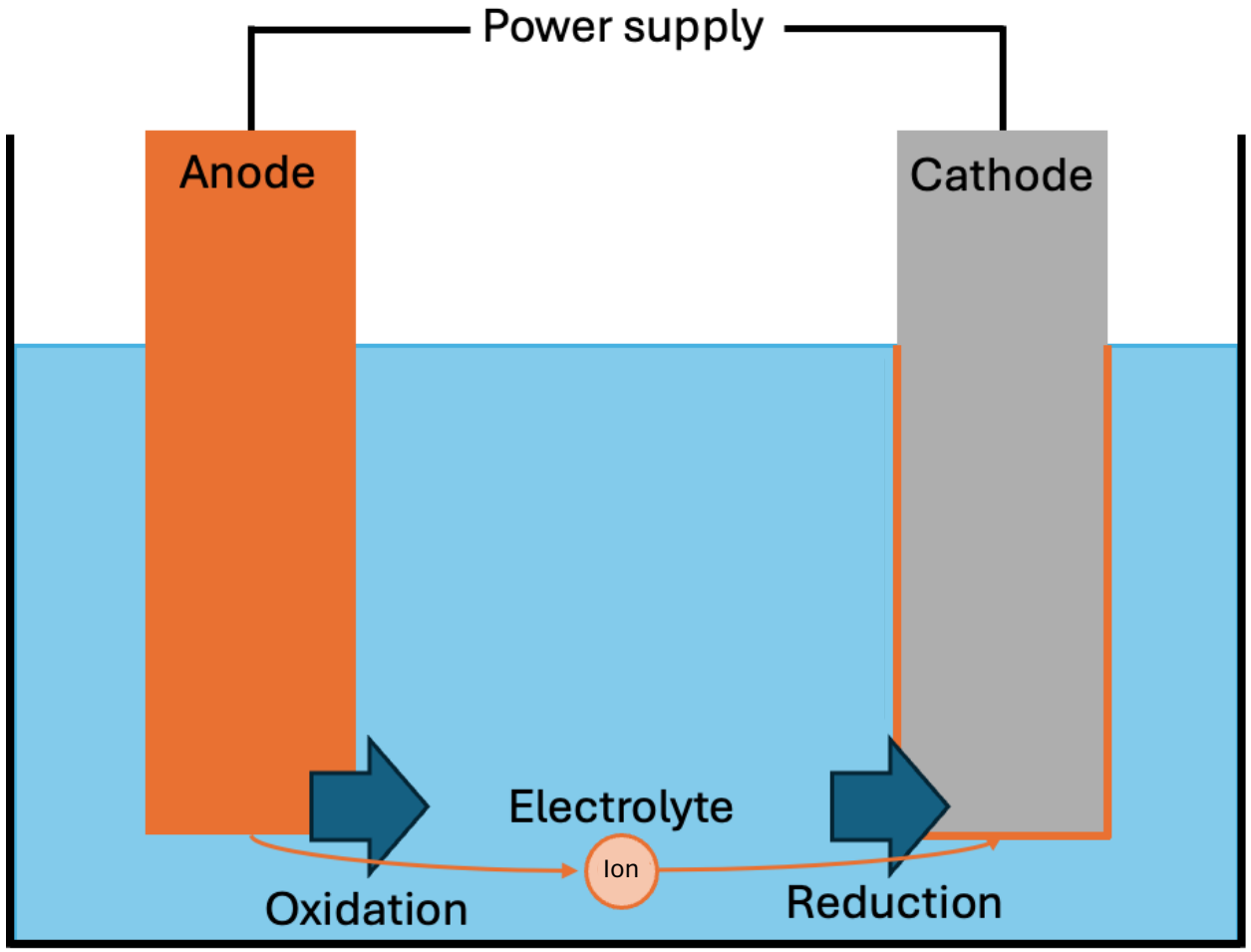
$$M = \frac{m_r \int \mathrm{I(t)\ dt}}{zF}$$

Molar mass

Current

No. e^-

Faraday constant



- Current depends on
  - Conductivity of solution -> electrolyte concentration
  - Electrode separation
  - Applied potential

Copper electrodeposition

- Species plating tendency governed by reduction potentials

$$E^0_{cell} = E^0_{\text{Cathode}} - E^0_{Anode}$$

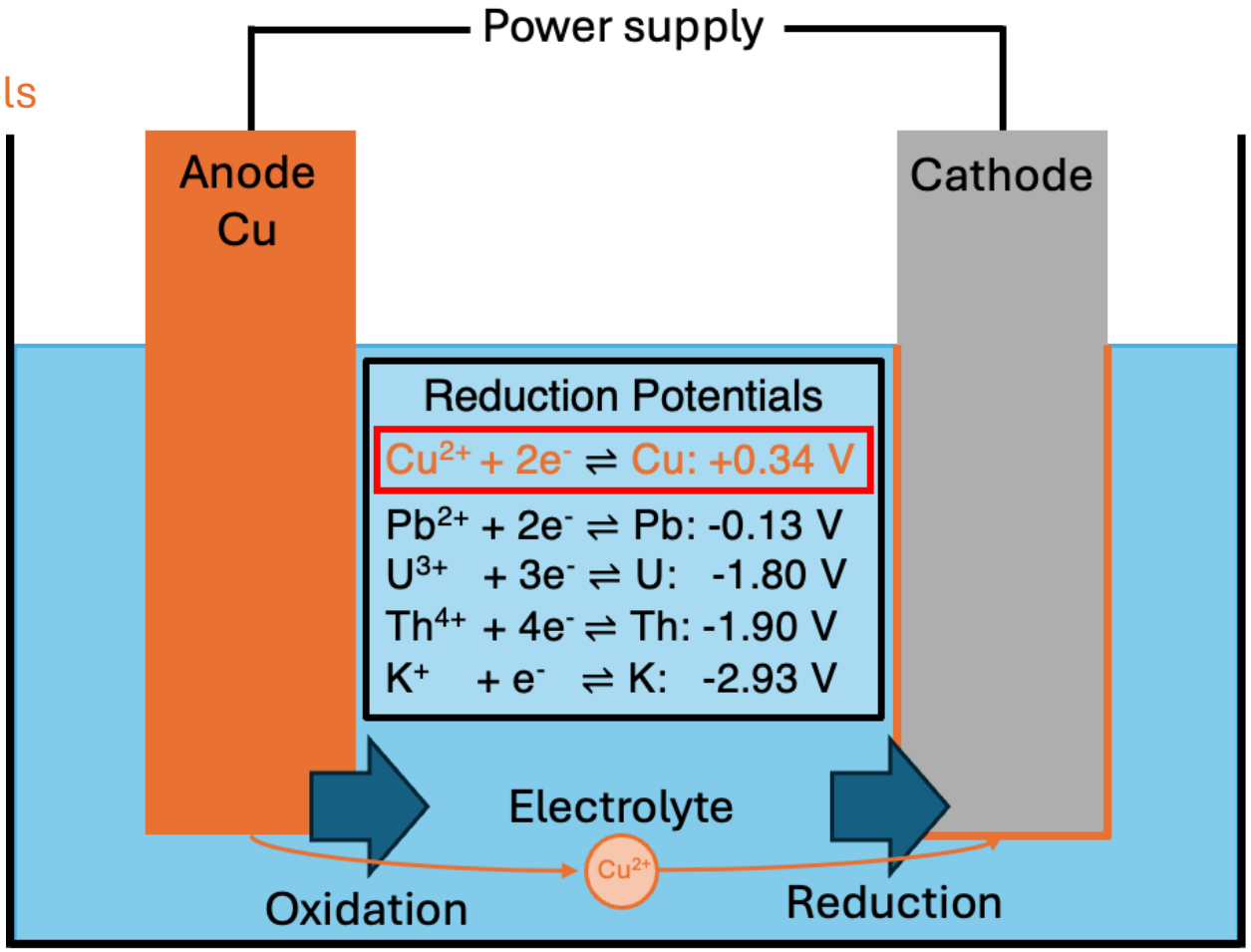
If $E^0_{cell} > 0$ reaction is spontaneous

Th^{4+} as an example:

$$E^0_{cell} = Th^{4+}(-1.9\text{V}) - Cu^{2+}(0.34\text{V})$$

$$= -2.59V$$

Cu^{2+}: $E^0_{cell} = 0\text{V}$



- Careful control of applied potential difference allows preferential plating of copper over contaminants
- Used in industry to produce copper with excellent purity

Ultra-pure copper electrodeposition

How this differs from industry – prioritise purity

- Procedure principally developed by PNNL for Majorana Demonstrator
- Additive free electrolyte
- Prioritise purity over speed -> careful voltage selection
- Cleanroom environment
- Stringent radiopure material and reagent selection
- Purity monitoring
- Comprehensive cleaning procedures built over years of PNNL experience

  NIMA 579 (2007) 486-489
  RCTR 277 (2008) 103-110
- Plating underground -> reduce cosmogenic activation

Cu preparation

Pipework preparation

Start with ultrapure pipework used in Si industry

↓

Circulate nitric acid to leach plastic of contaminants

↓

Constant solution filtration

Cu preparation

Start with commercially pure copper feedstock

↓

Remove surface contaminants
Micro-90 followed by etching with acidified peroxide

↓

Build copper sulphate electrolyte
Commercial too impure so electropolish our own

Results – ICPMS

Sample of copper	^{232}Th [uBq/kg]	^{238}Ur [uBq/kg]
Commercial C10100	8.7 ± 1.6	27.9 ± 1.9
NEWS-G plated copper *NIMA 988 (2021) 164844*	<0.24	<0.11
Majorana demonstrator electroformed *NIMA 828 (2016) 22-36*	<0.119	<0.099

- Orders of magnitude improvement over commercial copper
- Purity results often limited by available assay techniques -> can only set limits

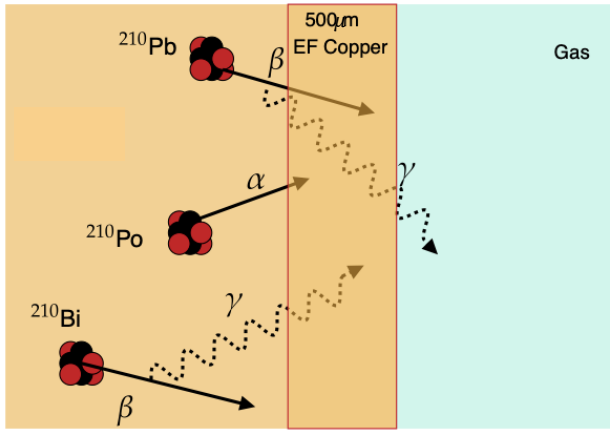
How this is/can be used for experiments

Electroplating

- Cu plated onto existing structure (i.e. cryostat) or components
- Acts as an ultra-pure shield
- Could be used to radon emanation

Electroforming

- Cu plated onto a mould (called mandrel)
- Remove the mandrel leaving a pure copper structure
- Construct large structures



NEWS-G electroplated Cu

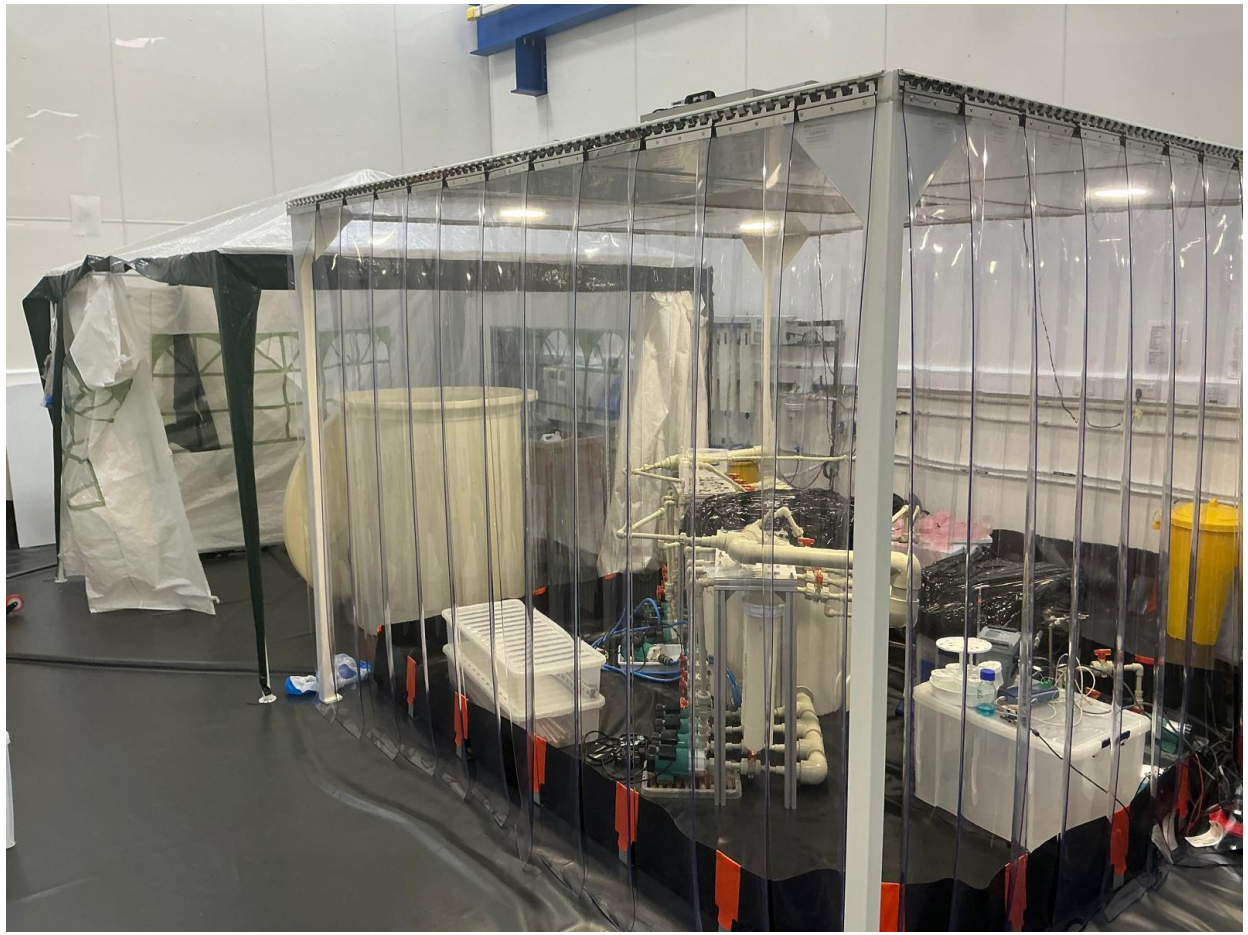
NIMA 988 (2021) 164844

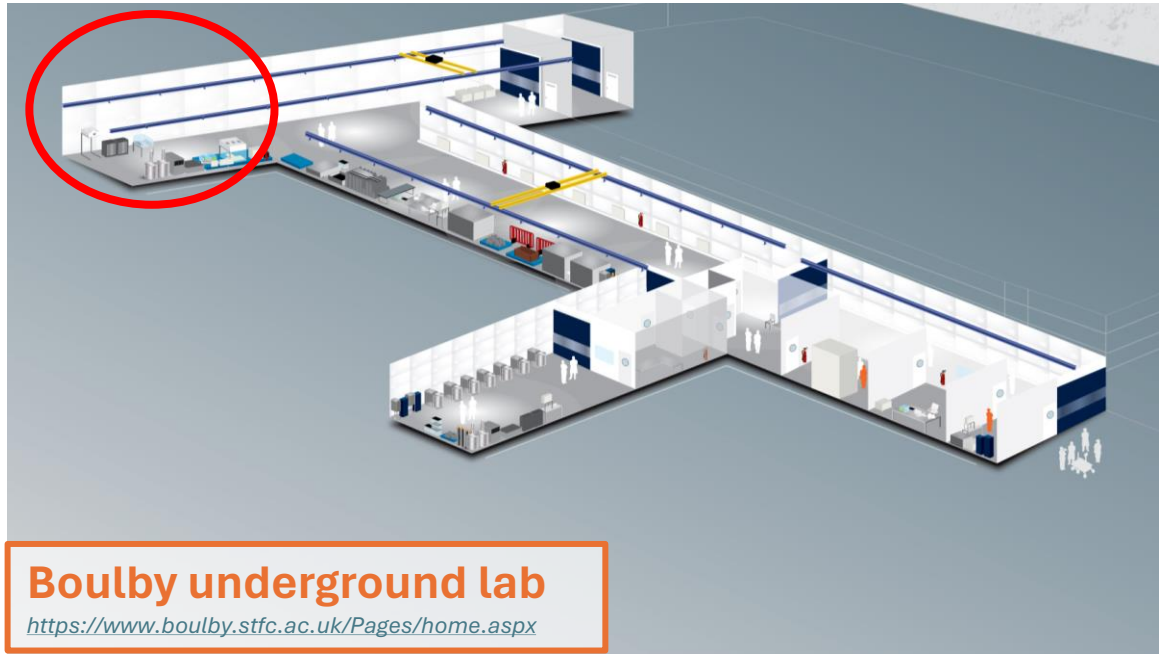
Majorana Demonstrator Electroformed Cu

OSTI (2012) 1039850

Electroforming facility at Boulby

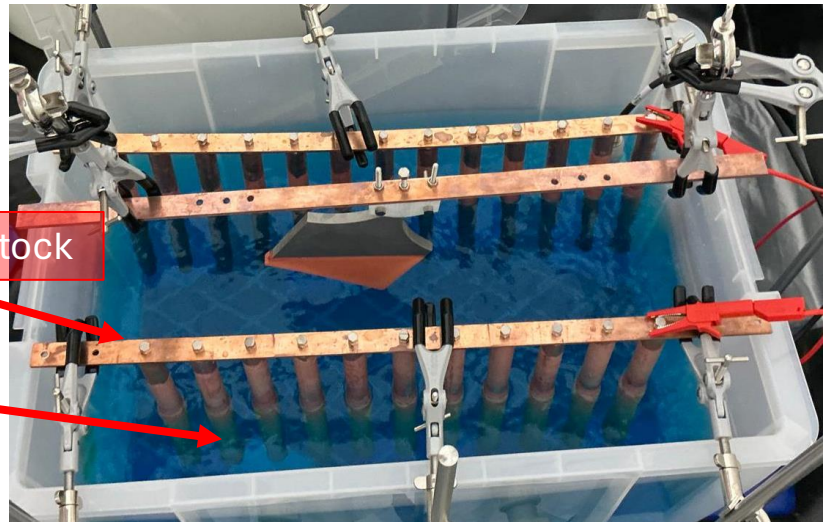
- 1.1km underground at the UK's deep underground laboratory Boulby
- Dedicated ISO-6 cleanroom within the larger Boulby cleanroom
- XIA UltraLow-1800 + ICP-MS on site at Boulby *Front. Phys. 2023 11:1310146* *JINST 2025 **20** P06010*

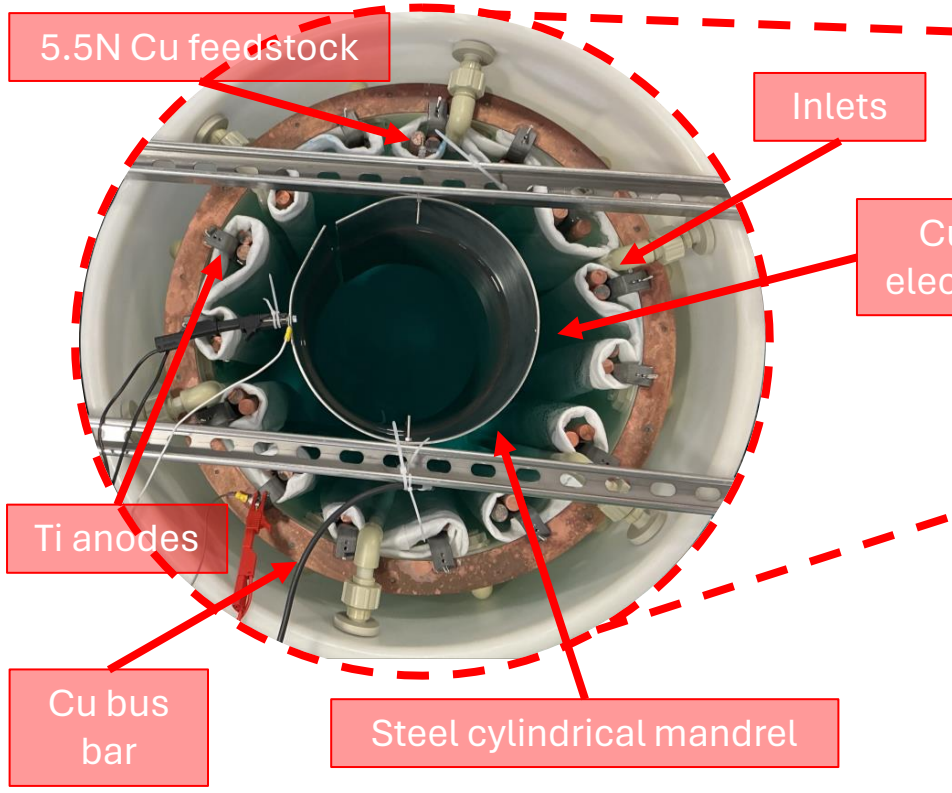


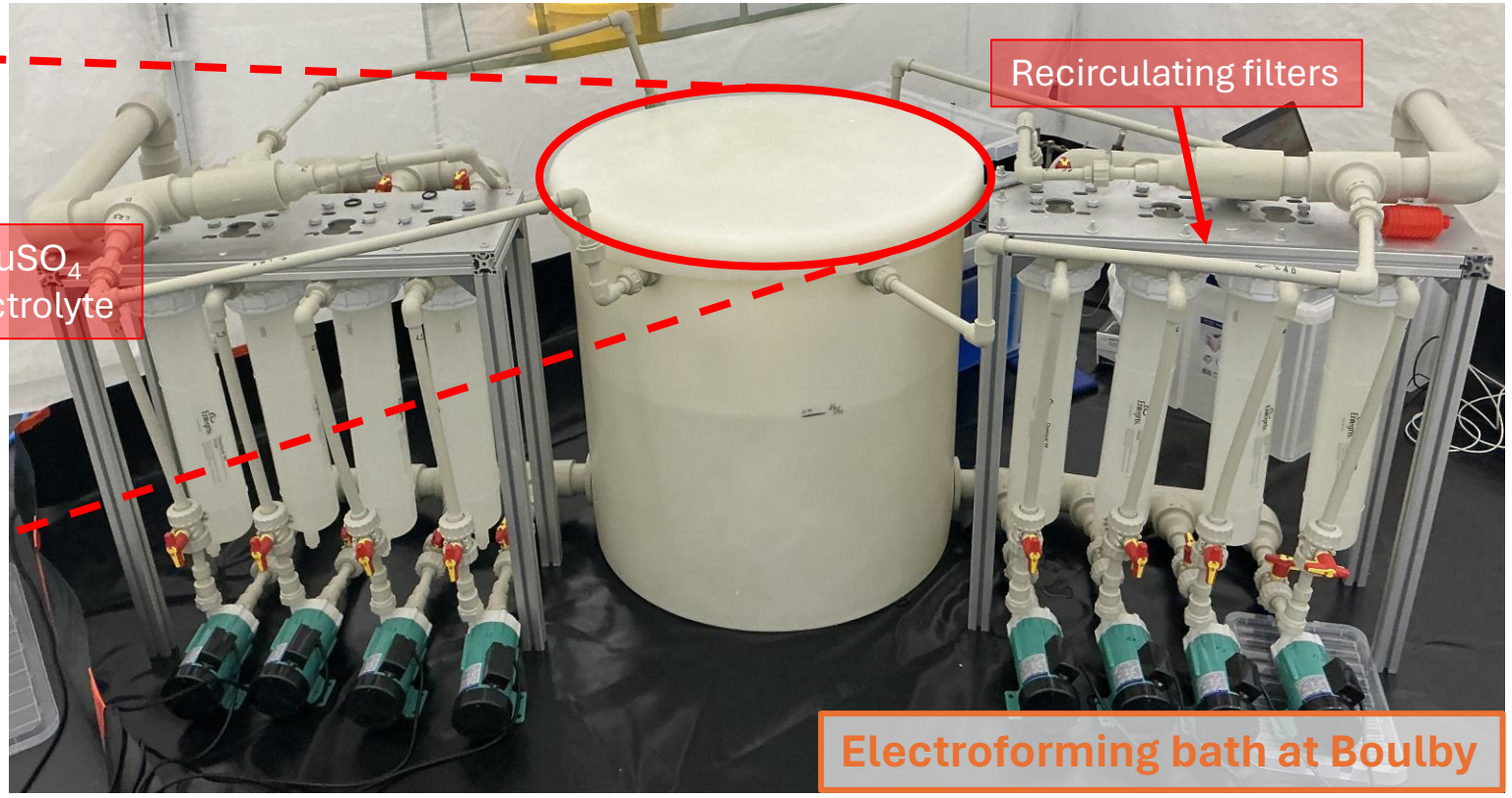


Electroforming facility at Boulby

- Small setup used to plate smaller components
- Larger setup's first goal to electroform a 30 cm spherical proportional counter: DarkSPHERE-30

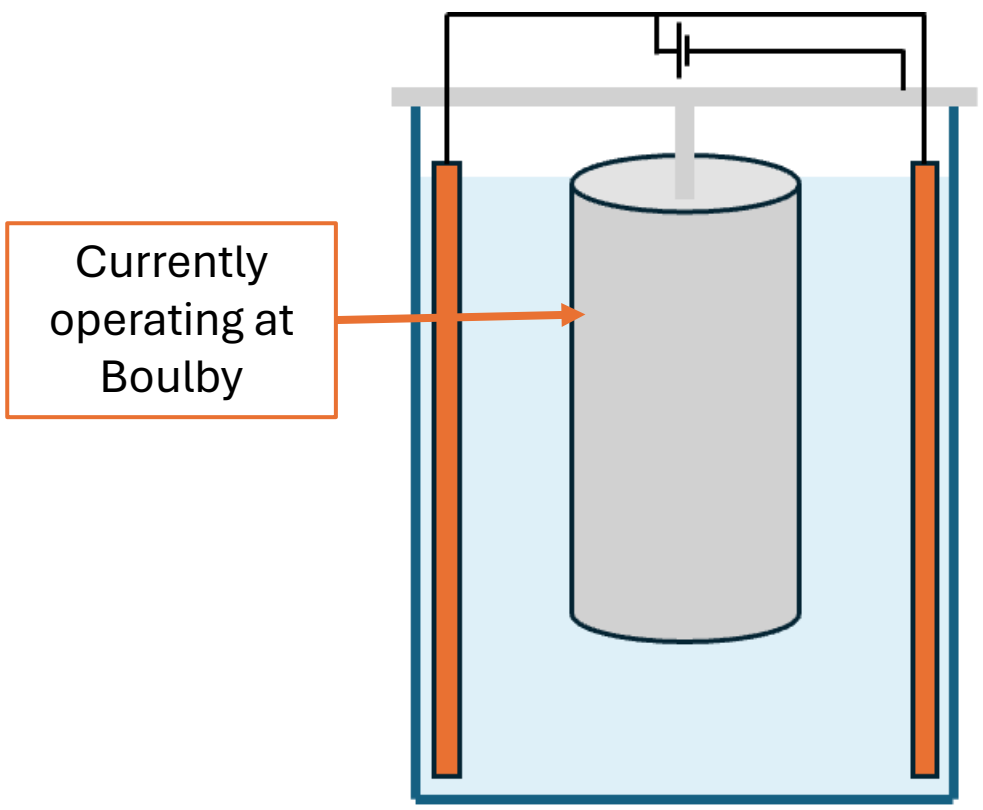


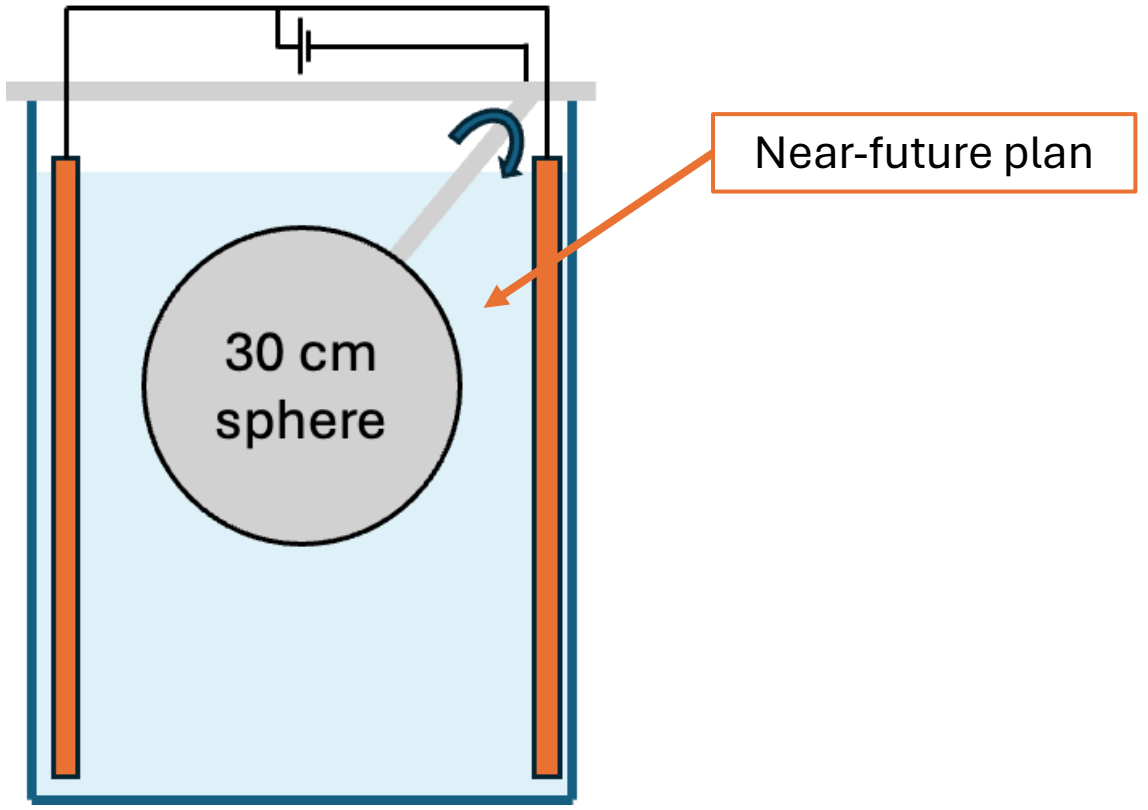




Electroforming facility at Boulby

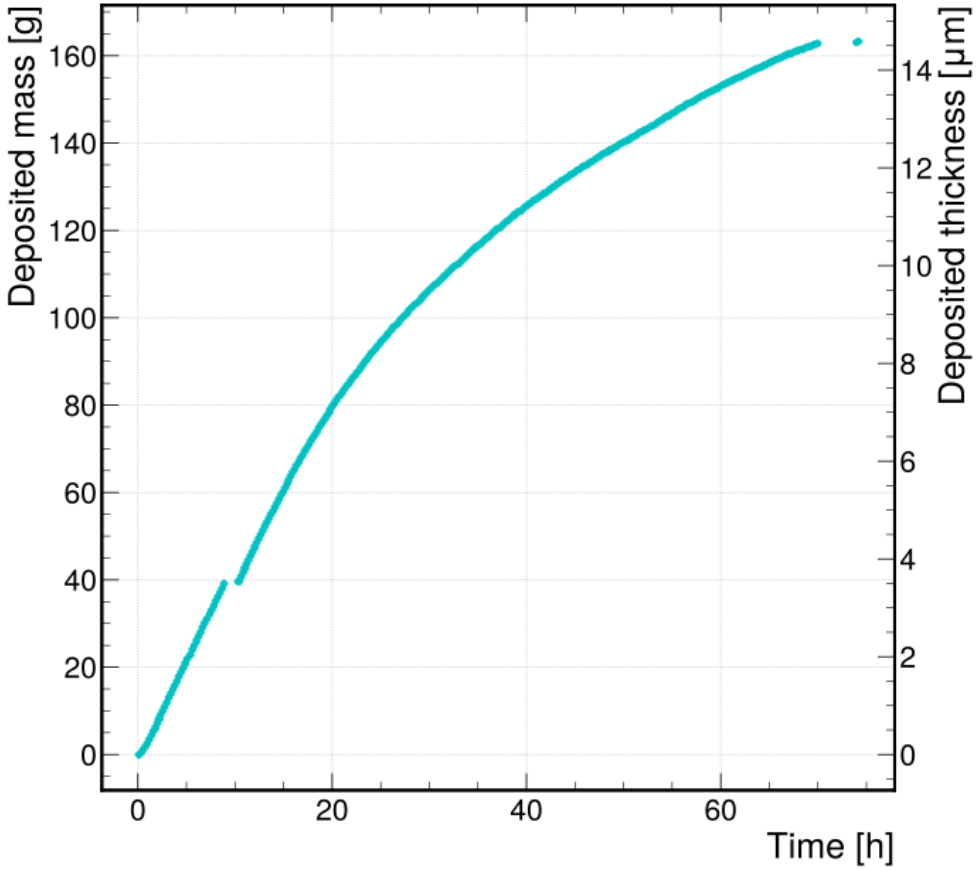
- Geometry of bath and electrodes important for uniform plating
- Large bath setup for depositing onto a cylindrical and spherical mandrels
- Copper removed from mandrel by thermal shocking if metal or chemically dissolving if plastic





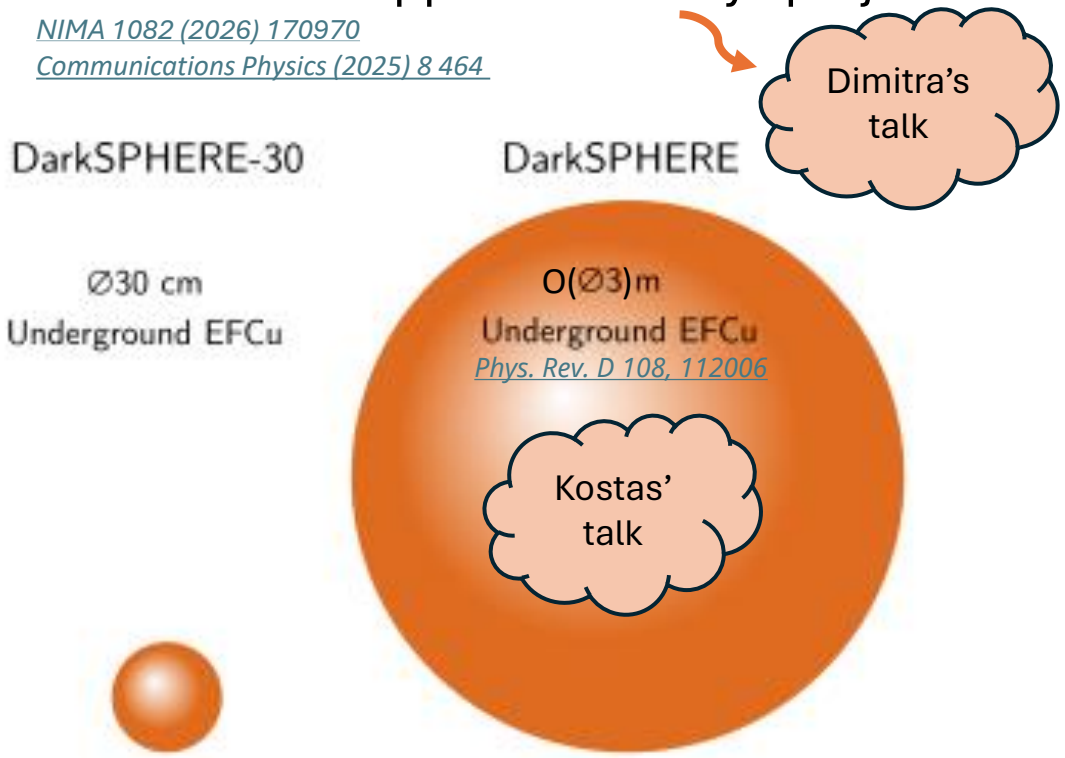
Current status

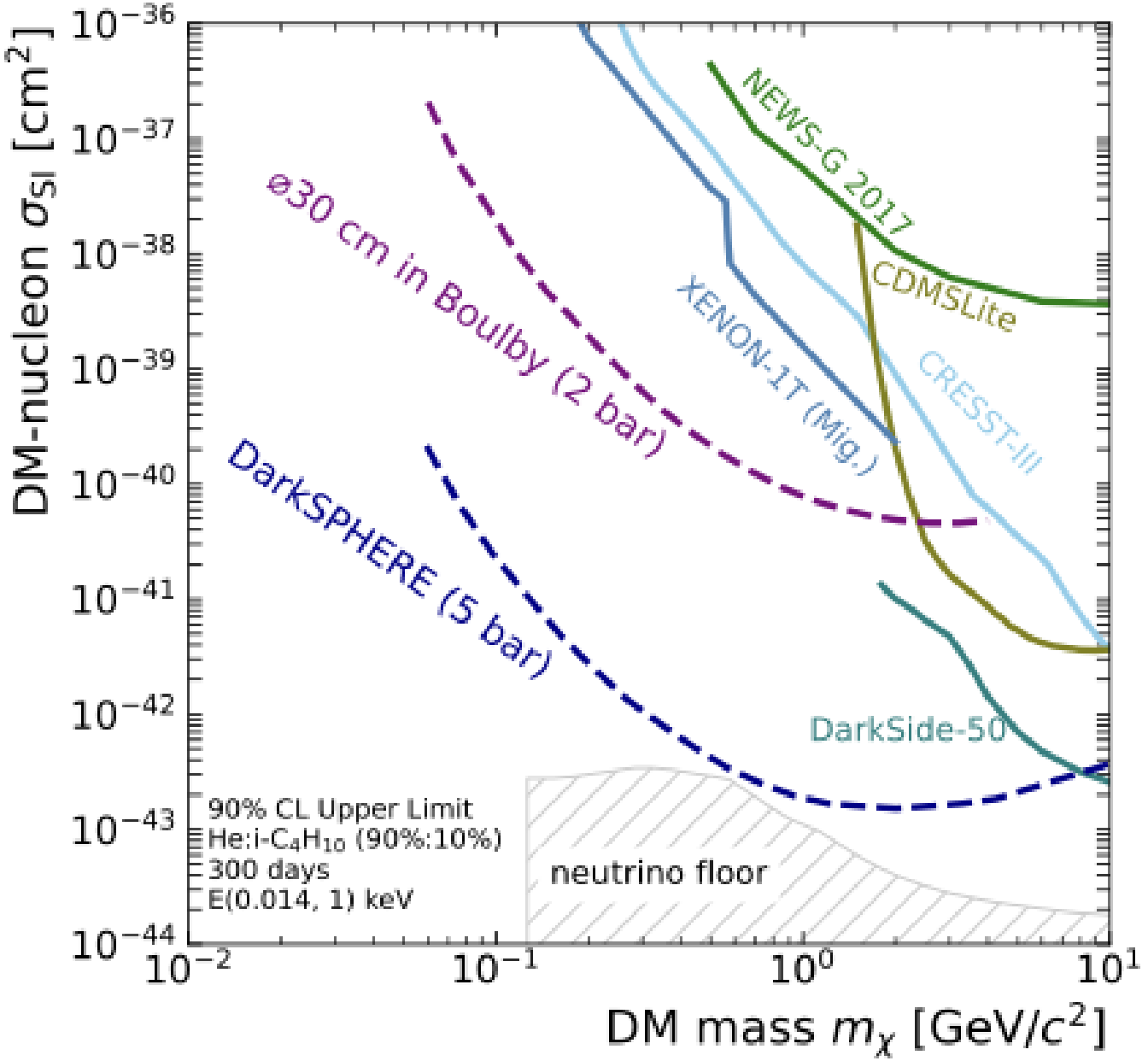
- Copper plated onto stainless steel cylinder
- Peeled copper off mandrel -> ICPMS and XIA results pending
- Can use flattened copper from cylindrical mandrel as tray for XIA

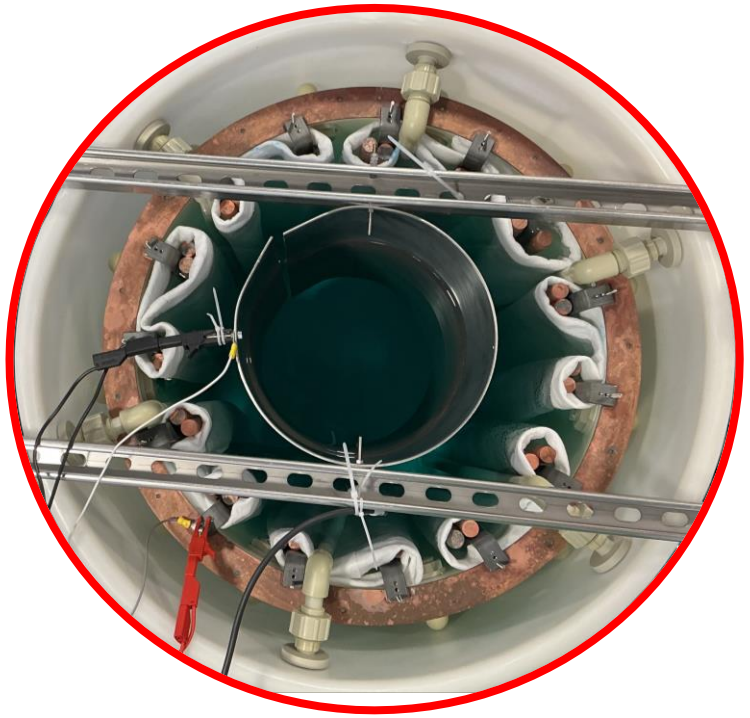
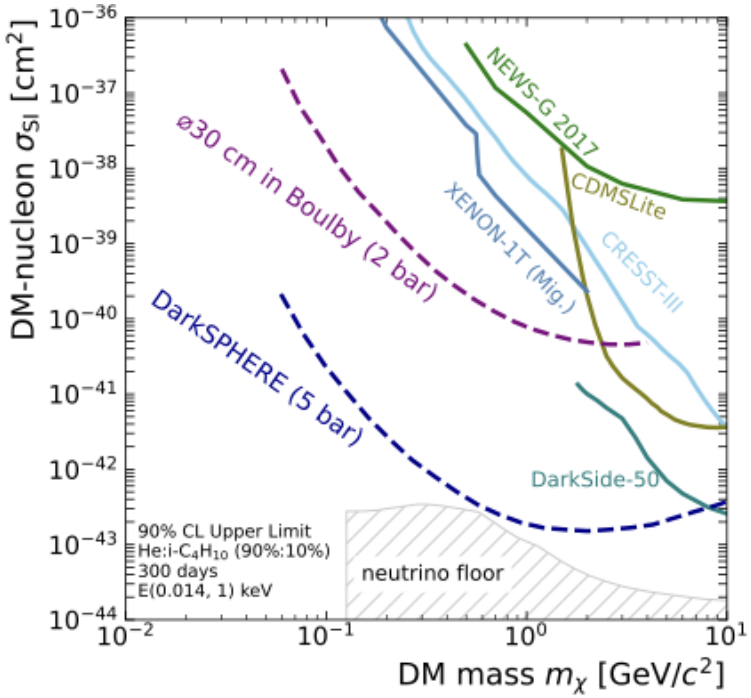


Physics Potential

- Fully electroformed spherical proportional counters will have world leading sensitivity to low-mass dark matter
- DarkSPHERE-30 will begin construction in the coming months
- Alloys being explored to improve the properties of electroformed copper – PureAloys project
  - *NIMA 1082 (2026) 170970*
  - *Communications Physics (2025) 8 464*





Summary

- Copper electroforming for radio-pure detectors
- Orders of magnitude improvement in radiopurity over commercial Cu
- Electroforming facility constructed at Boulby
- First copper produced
- Electroforming a ⌀30cm SPC in the coming months
- Many experiments exploring the use of electroformed and plated Cu