DarkSPHERE and Electroforming in Boulby

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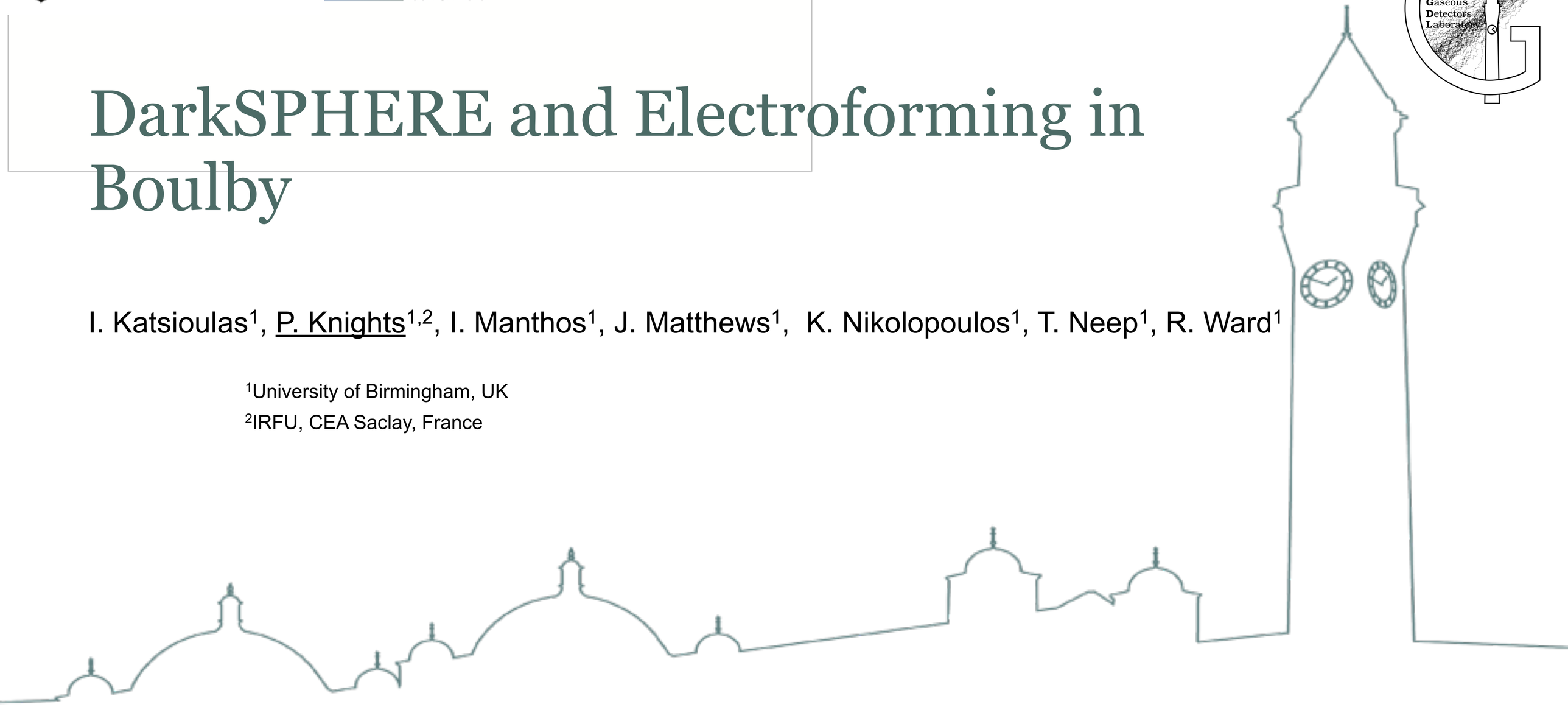


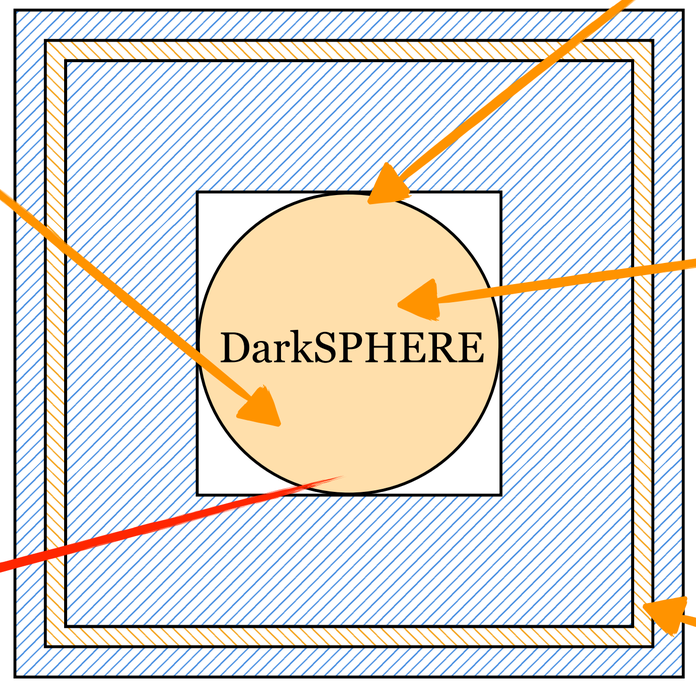
DarkSPHERE

⌀3 m fully underground-electroformed detector

Operation with 5 bar $He:C_4H_{10}$ (90%:10%)

(27 kg)

➡Large mass of light targets



Multi-anode readout with potential for individual anode read-out (TPC-like mode)

➡Studying in simulation

Multi-physics potential

- Dark Matter search
- 0ν2β decay search
- CEvNs physics

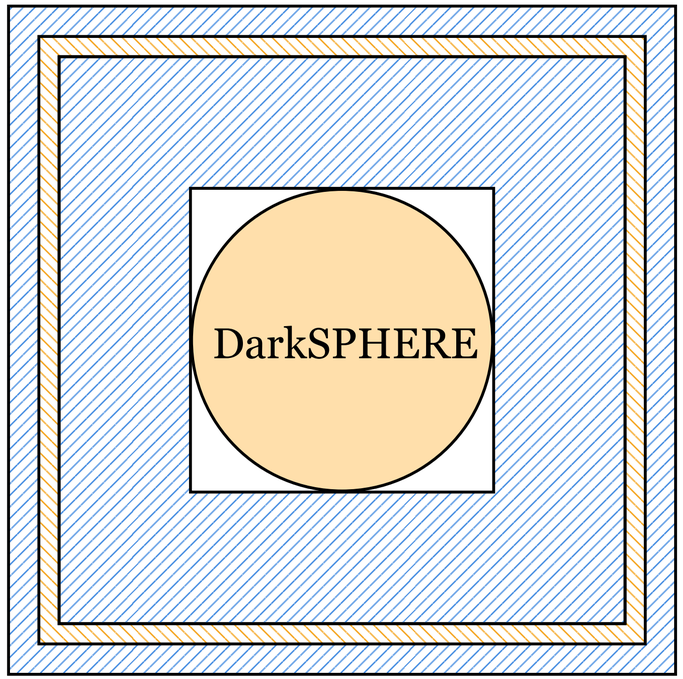
Would like a water shield 3.5 m (footprint: 10x10x10 m^3)

If space not available: 1.3 m water + 0.2 m lead +0.3 m water shield

➡Fits in current lab

DarkSPHERE

⌀3 m fully underground-electroformed detector



- **Timeframe**: 5 years (design, construction) and then exploitation
- **Footprint**: 10x10x10(7x7x7) m^3 + workspace, gas bottles etc. (in close proximity)
- **Depth:** Either depth works, but require cleanroom
- Considerations:
  - Containment of water in case of leak
  - Proposed gas is below flammability limit
    - Good ventilation required
  - HV (<10kV detector bias)
  - Pressure certification
  - Shielding cover gas - N2
- No underground machining envisaged
  - Detector EF as one piece, with flange built in
- Electroforming will take ~ 1-1.5 year
- Active muon veto desirable, but not essential
- Cost: ~2 M £ (inc. personnel) roughly equally shared over 5 years

Copper as a Construction Material

- Copper is a common construction material for rare event experiments:
  - Strong enough to build gas vessels
  - Commercially available at high purity
  - Low cost
  - No long-lived radio-isotopes
    - Longest ^{67}Cu $t_{1/2}$ = 62 hours
  - Possibility to electrochemically purify
    - ‘electrowinning’

DAMIC

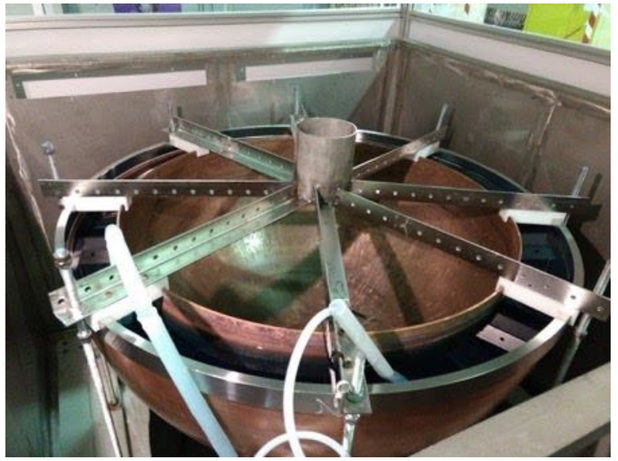
https://www.pnnl.gov/science/highlights/highlight.asp?id=1434

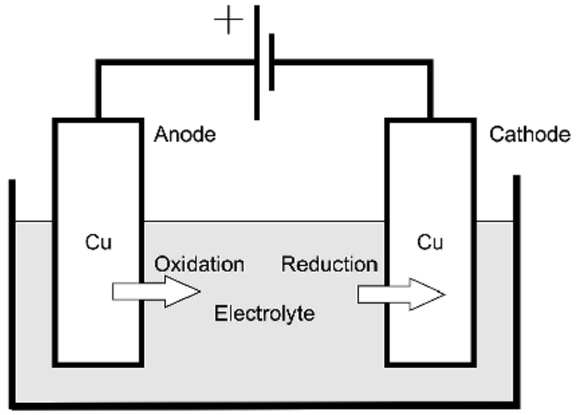
Experiments which use/will use copper in detector:

- DAMIC
- SuperCDMS
- DarkSide-20k
- NEWS-G
- nEXO
- Majorana
- DARWIN
- LZ
- …

Electroforming

- Electrolysis: oxidation and reduction reactions
  - Ions reduced at cathode building up material
- Current supplied to drive reactions
- Mass deposited proportional to current supplied
- Copper has higher reduction potential than Uranium, Thorium, Lead...
  - **Copper refined during electroforming**
- Can be used to coat materials or completely form them (plating to a mandrel)





EF Radiopurity and Assay Techniques

- Underground electroformed copper
  - Cosmogenic activation minimised
  - Minimised ^{222}Rn contamination found with commercial coppers (Lowest in Boulby!)
- Generally assayed with
  - ICP-MS
  - XIA UltraLo-1800 (Available in Boulby!)
- Electroformed copper used for sample trays of XIA UltraLo-1800
- SNOLAB has invested in ECUME facility for electroforming
  - Worlds largest underground EF facility
- Canfanc have Copper Electroforming Service (surface)
- Boulby can capitalise on R&D/experience for NEWS-G/ECUME

ICP-MS Assay
(Majorana Demonstrator + NEWS-G)

Copper Type	^{232}Th [*μBq/kg*]	^{238}U [*μBq/kg*]
C10100 (99.99% OFHC)	1.2±0.3	2.5±0.7
C10100 (Machined)	8.7±1.6	27.9±1.9
Electroformed	<0.12	<0.10
Electroformed (Machined)	0.5±.1	0.50±0.03
Electroplated (NEWS-G)	<0.58 <0.24	<0.26 <0.11

Majorana Demonstrator: NIMA 828 (2016) 22-36
NEWS-G: NIMA 988 (2021) 164844

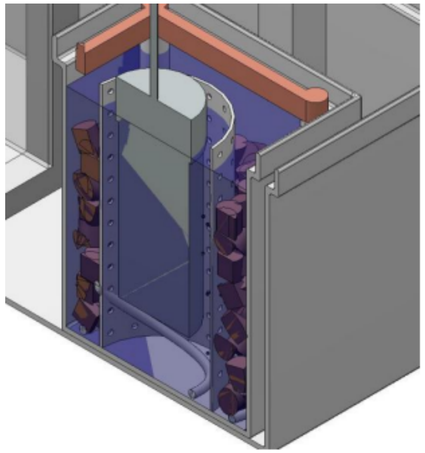
XIA UltraLo-1800 Assay 10.1063/1.5018989

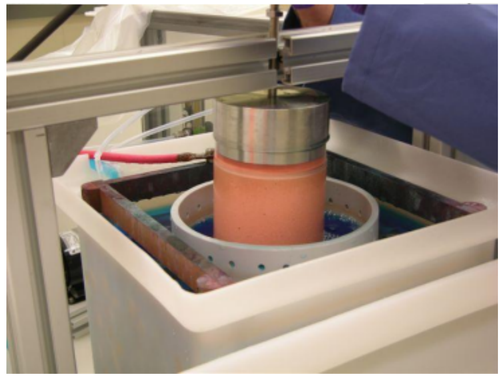
Sample	^{210}Pb contamination (mBq/kg)	^{210}Po contamination (mBq/kg)
OFC#1 (C1020) (MMC)	40±8	47±21
OFC#2 (C1020) (MMC)	20±6	33±14
OFC#3 (C1020) (MMC)	27±7	$(1.6\pm0.3)\times10^{2}$
OFC#4 (C1020) (MMC)	23±8	$(2.2\pm0.4)\times10^{2}$
OFC#5 (C1020) (SH copper products)	17±6	44±18
OFC#6 (C1020) (SH copper products)	27±8	24±17
OFC (class1) (SH copper products)	36±13	38±3
Coarse copper (MMC)	$(57\pm1)\times10^{3}$	$(16\pm2)\times10^{3}$
Bare copper (MMC)	8.4±4.0	$(1.1\pm0.2)\times10^{2}$
OFC (MMC)	23±8	$(1.3\pm0.3)\times10^{2}$
6N copper (MMC)	<4.1	<4.8
Electroformed copper (Asahi-Kinzoku)	<5.3	<18

EF Facility: Space Requirements

- Should be placed in **cleanroom** - 1100 m depth is adequate
- Bath **footprint**: ~4x4x4 m^3 - suits DarkSPHERE but is large enough for wide range of uses
  - **Fits in current lab**, but set-up could **easily be moved** between labs (forklift?) if more convenient
    - Set-up can be **stored when not in use**
  - EF parts **can be moved outside clean area** if properly packaged
- Bath for could be used to form variety of shapes
  - Parts can be formed directly or machined (desirably underground)
- Crane usage needed for larger parts
- Bath should be contained in spill container
- Seismic activity should be low in Boulby

Example Majorana and PNNL baths





From: Ultra-high-purity Copper Technology Update, C. Aalseth, June 2007

PNNL electroforming baths

Material, Equipment & Personnel Requirements

- Potentially hazardous chemicals
  - Sulphuric acid (electrolyte)
  - Hydrogen peroxide (etching)
  - Citric acid (surface passivation)
  - Copper sulphate (produced, in electrolyte)
- No vapour/fume from electrolyte
- No aerosol generation
- Also requires pure water (18 MΩ cm) - already proposed for AIT?
  - A filtration facility can be installed and is asset for future experiments
- Cover gas - nitrogen

- Power supply (high-current O(100A), low-voltage O(1V), high-precision in both
- Conductivity monitoring

- Operation could be maintained by 1 person
- Surface requirements are minimal:
  - chemical storage

Summary

- DarkSPHERE offers broad reaching physics potential
  - Neutrino-floor reaching capability in sub-GeV DM search
- Ideally, full water shield if space allows
  - Shielding explored for housing in current lab
- DarkSPHERE is a medium size project
  - Experience gained in hosting it is a stepping stone for hosting larger scale experiment
  - Capabilities/facilities required are all assets for attracting future experiments
- Boulby can benefit from NEWS-G/ECUME experience to develop electroforming facility
  - R&D, vertical access of parts, plating parameters etc.
  - STFC funding awarded for feasibility/cost/scope study