



UNIVERSITY OF
BIRMINGHAM

Reaching the neutrino floor for sub-GeV dark matter with spherical proportional counters fully electroformed underground

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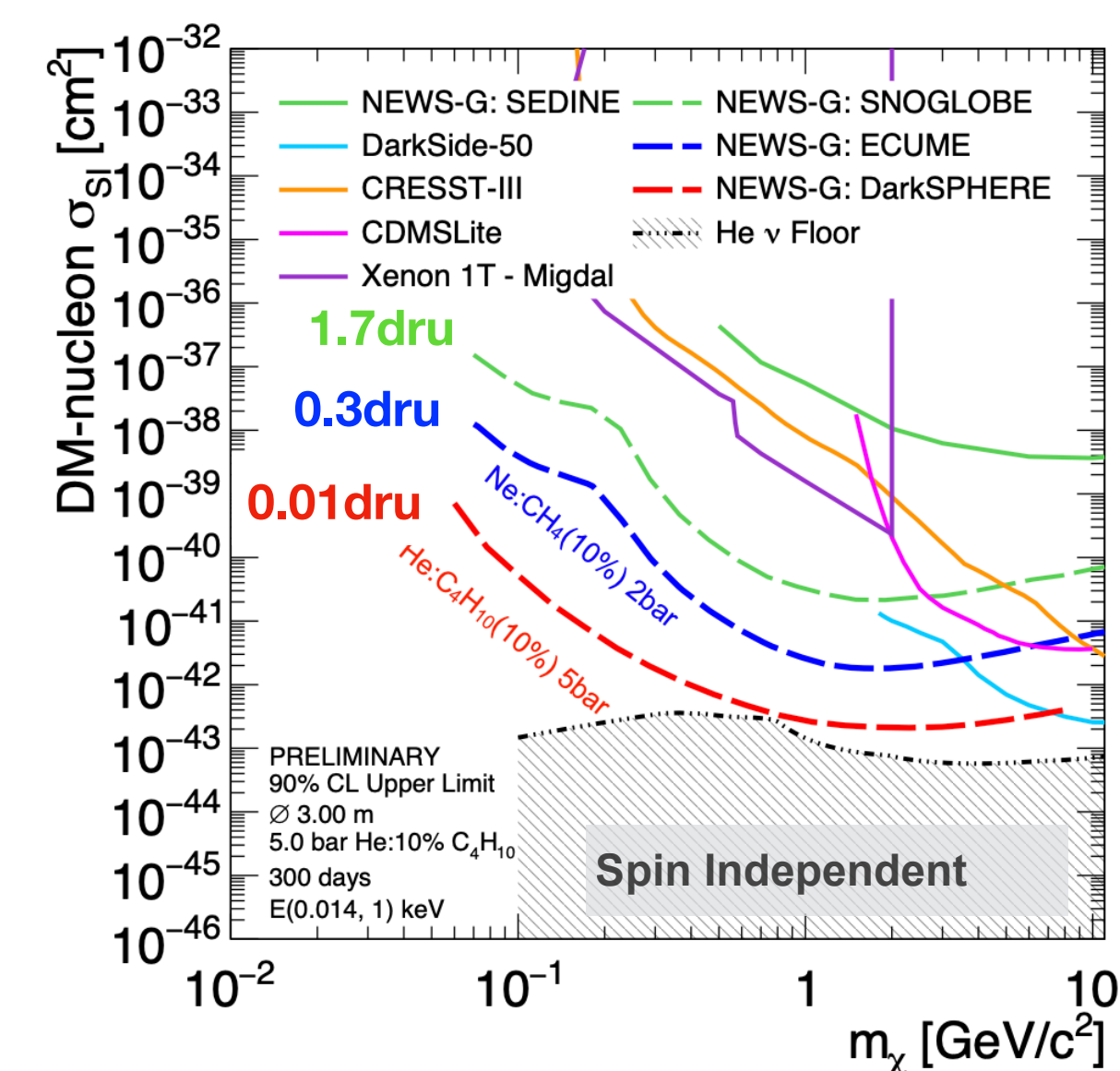
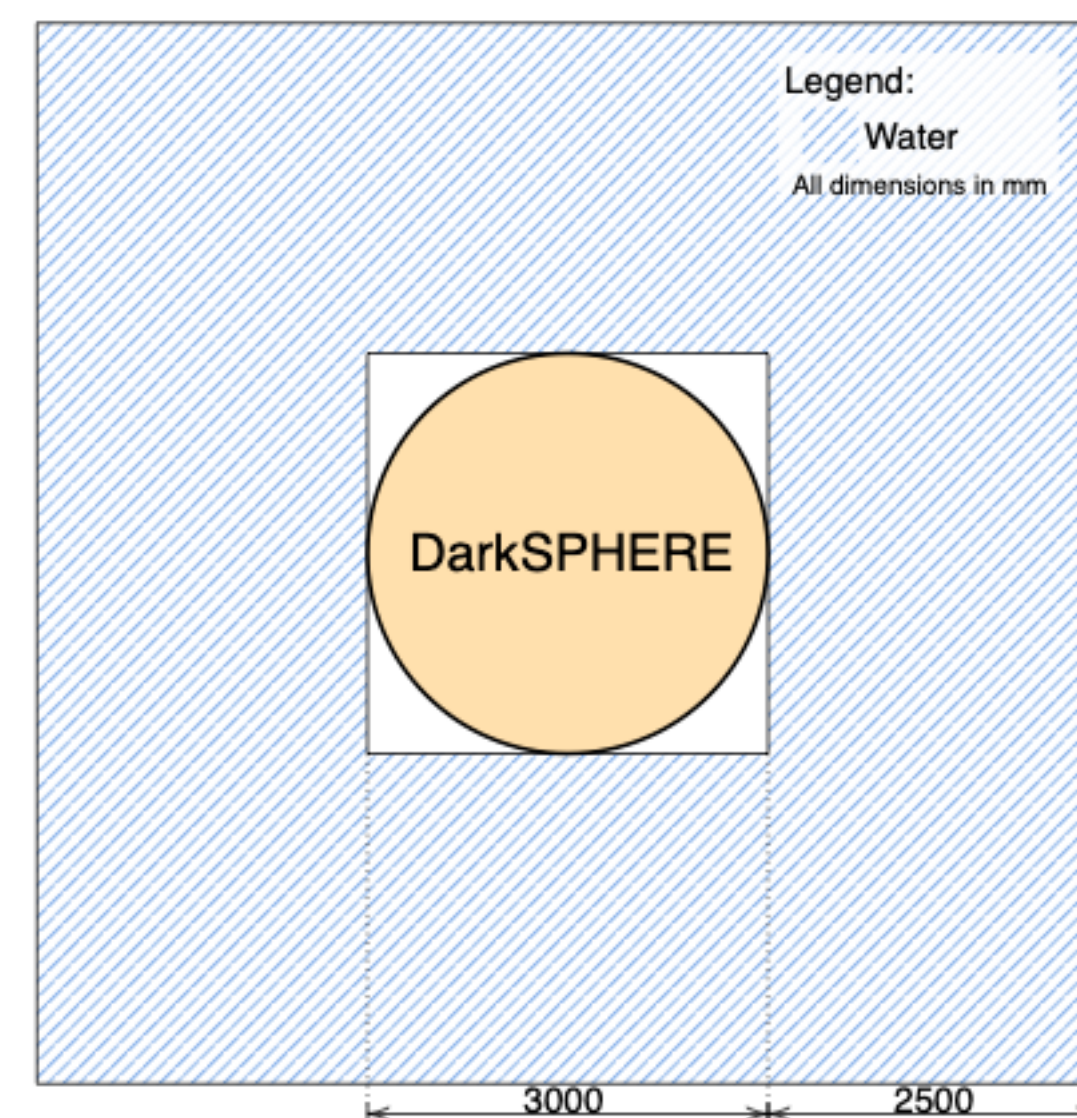
i.katsioulas@bham.ac.uk

Tuesday, April 5th 2022

IOP Institute of Physics

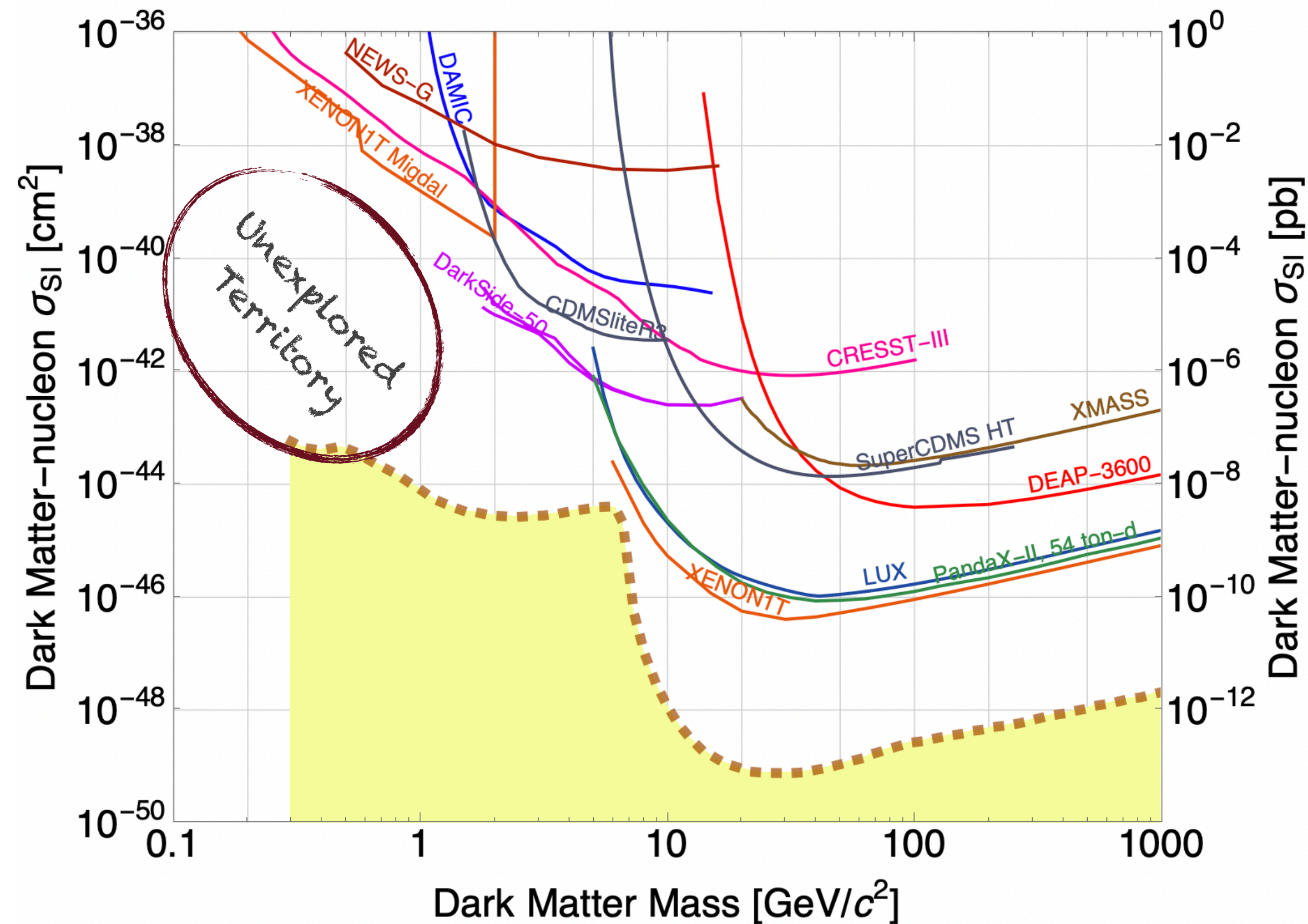
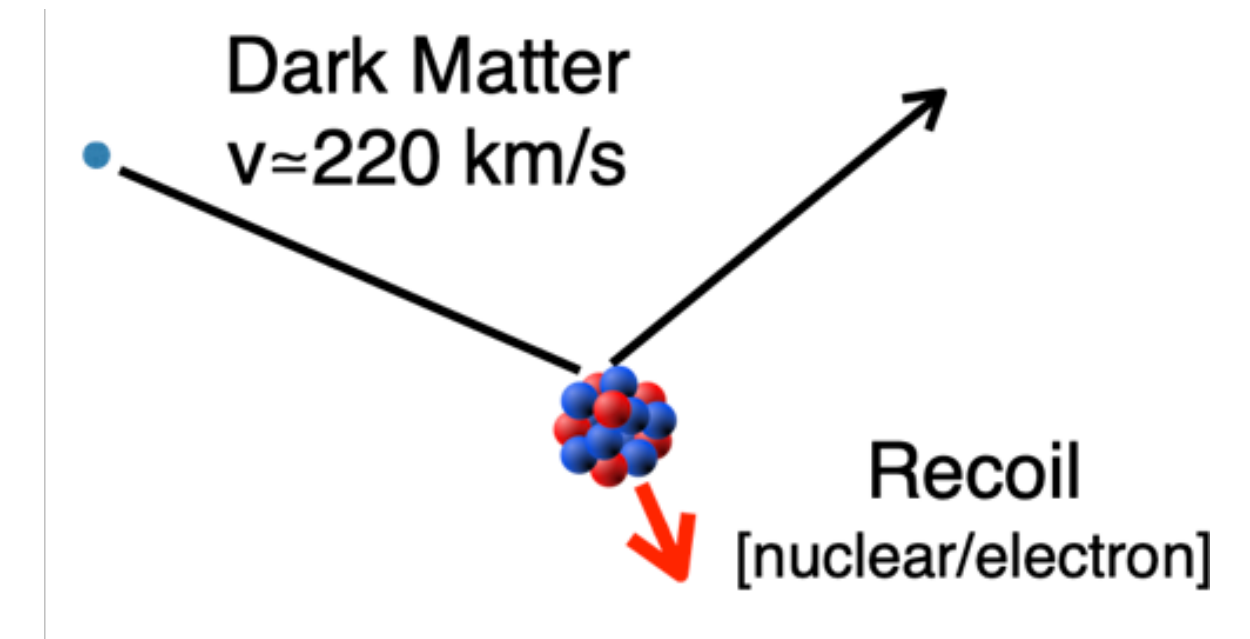
HEPP & APP Annual Conference 2022

3-6 April 2022, Rutherford Appleton Laboratory STFC, Oxfordshire, UK



Low mass dark matter searches

Going beyond the state-of-the-art



● Search for DM candidates in 0.05 - 10 GeV range

● Direct Detection experiment

► Novel detectors required that:

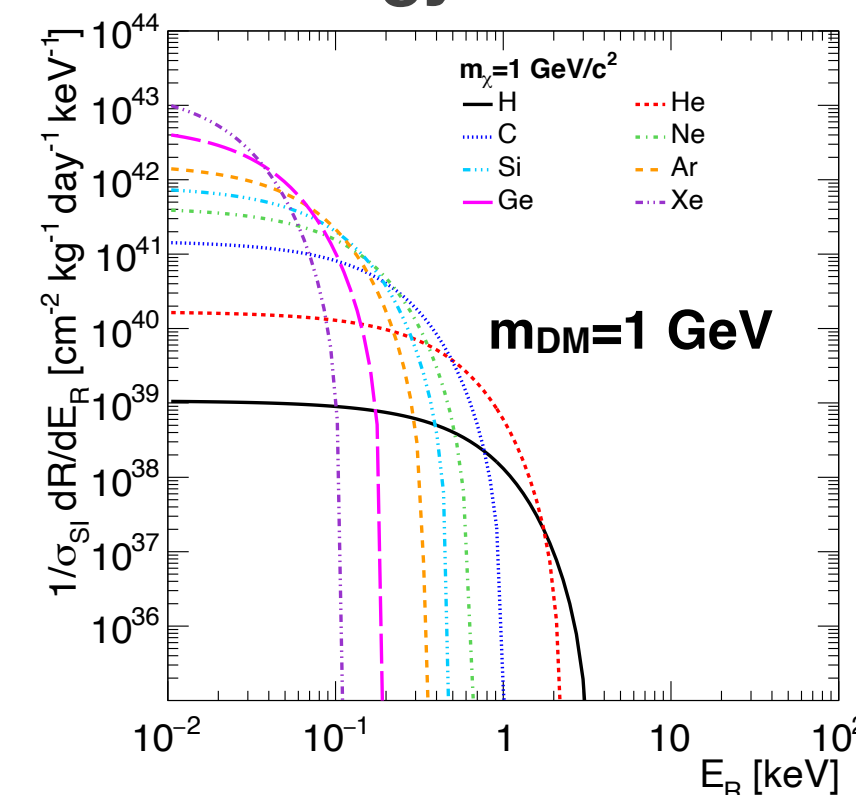
► Use light targets (H, He, Ne)

► Better projectile - target kinematic match

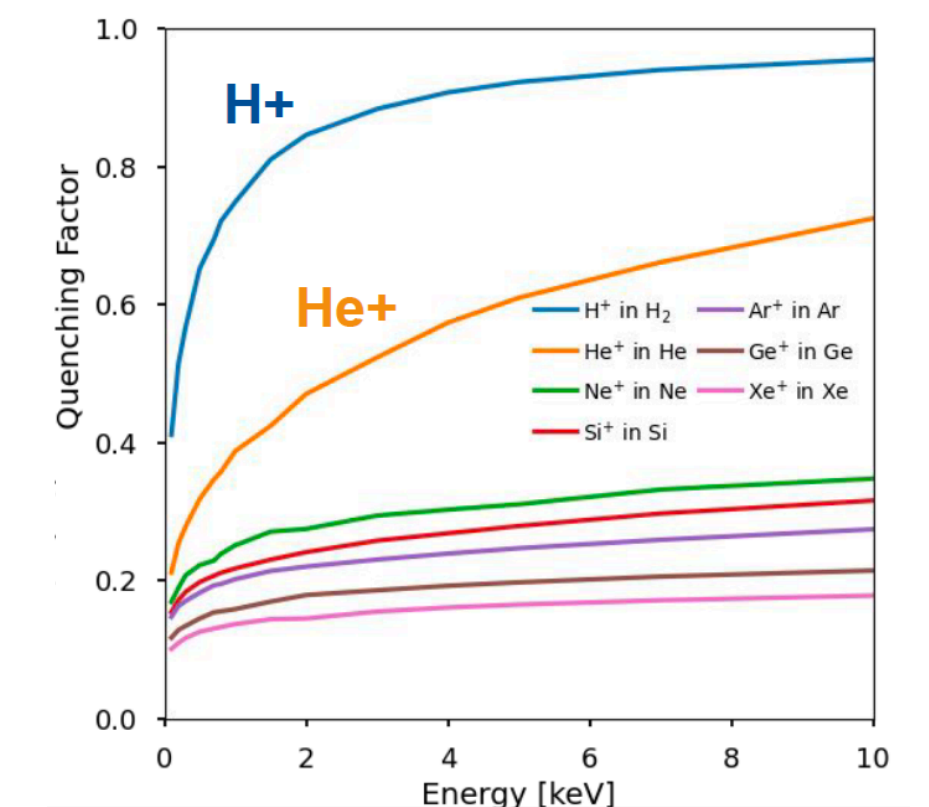
► Low energy threshold

► Favourable quenching factor

Recoil energy distribution

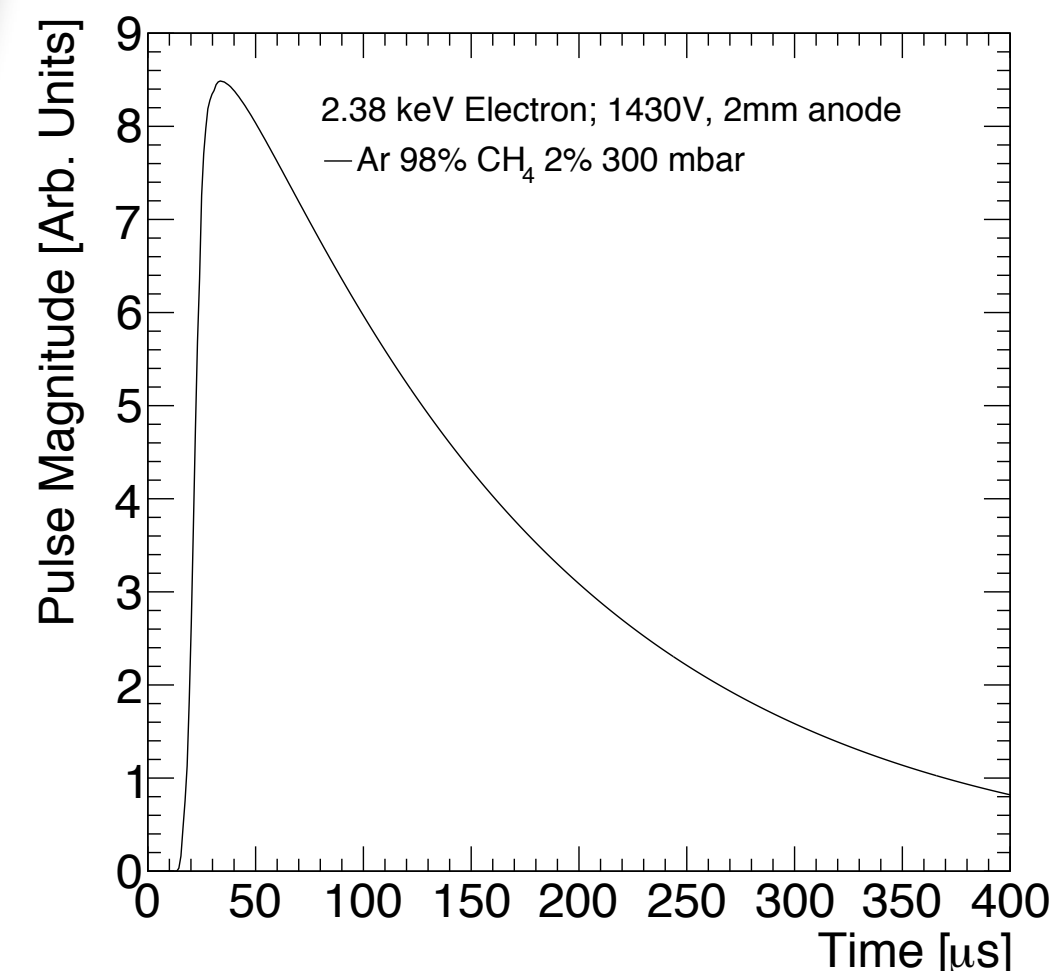
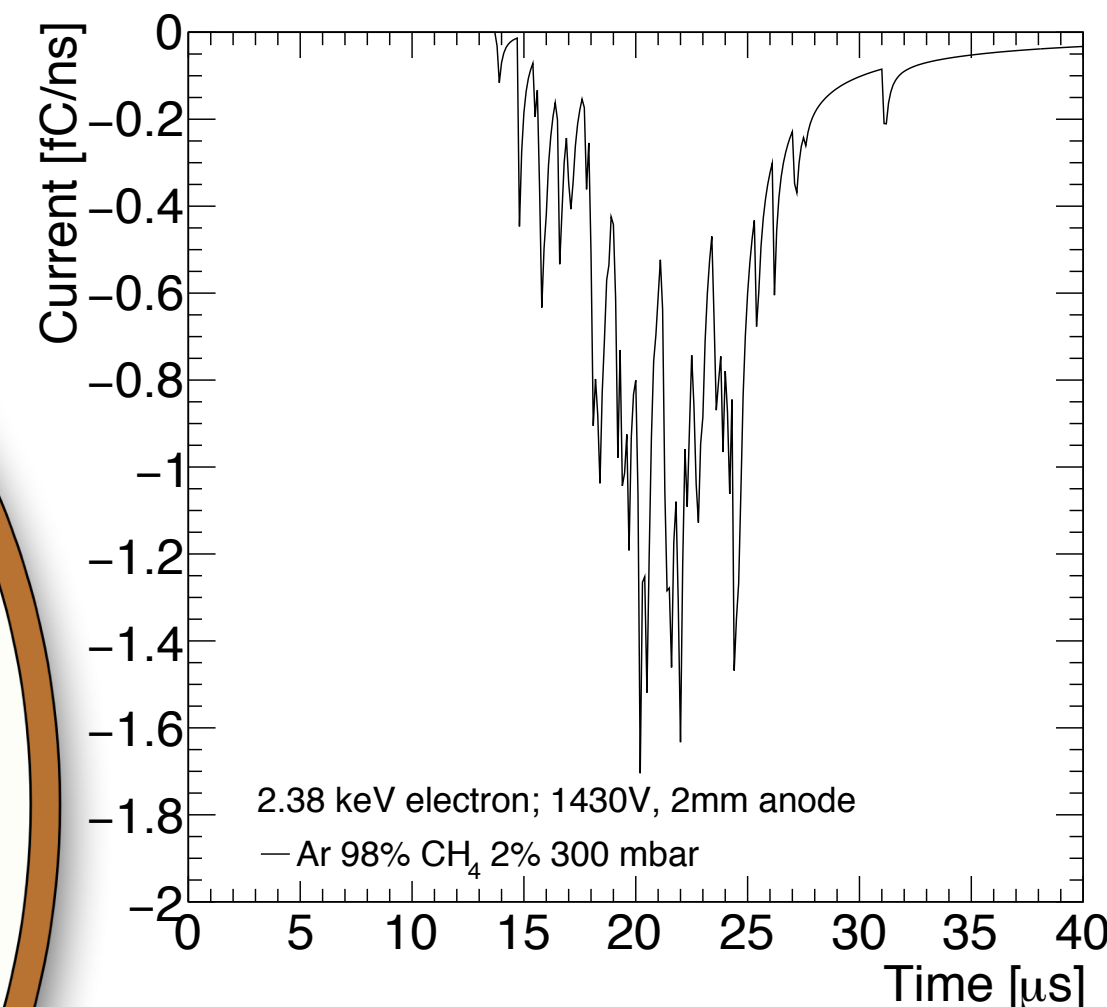
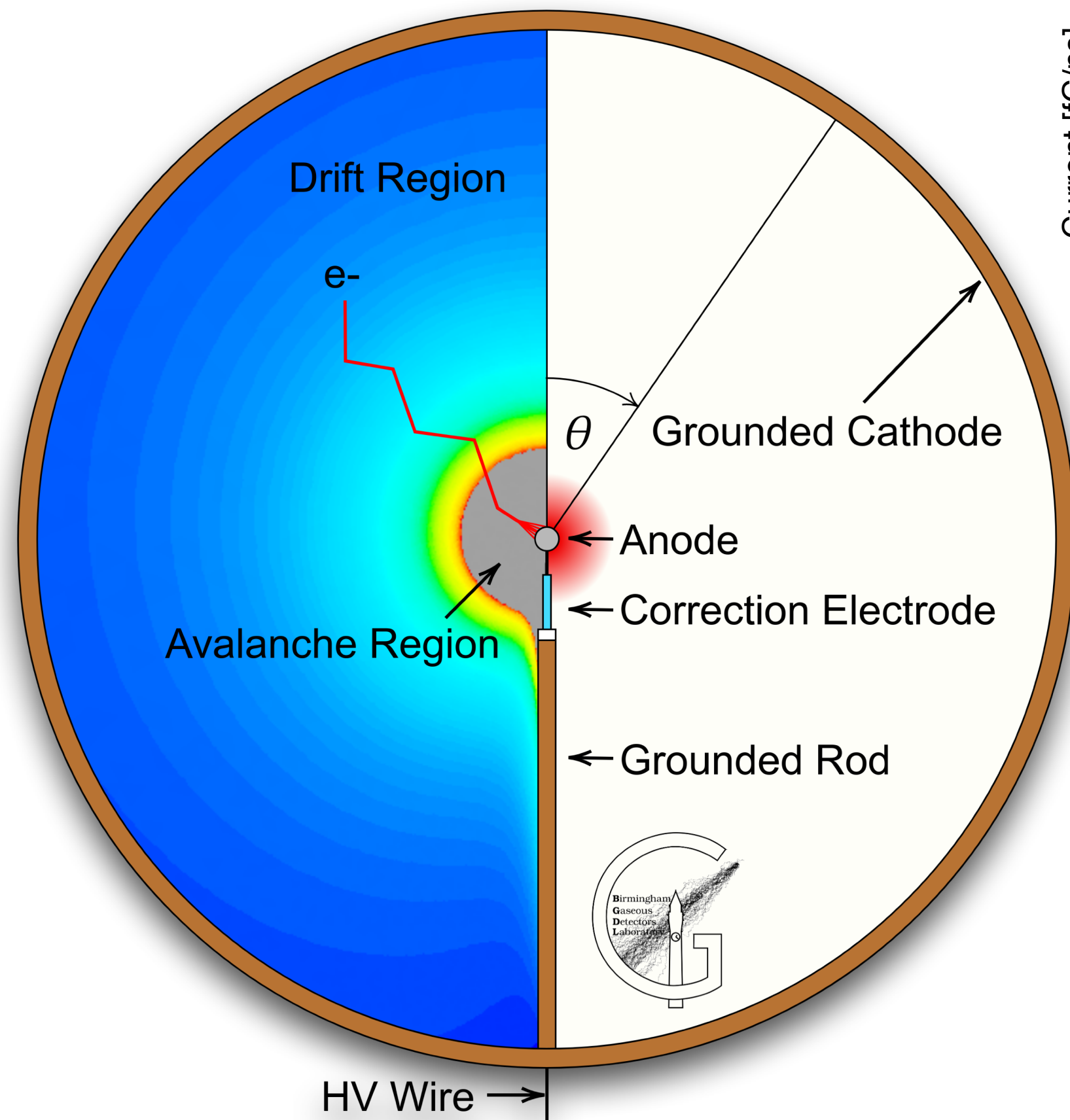


SRIM estimated quenching factors



The Spherical Proportional Counter

An innovative gaseous detector for rare event searches and applications



- **Electric field scales as $1/r^2$** , volume divided in: “**drift**” and “**amplification**” regions
- **Capacitance independent of size**: low electronic noise → single electron threshold
- **Simple design**: construction solely by radio pure materials
- **Event discrimination through pulse shape parameters**: Background discrimination and fiducialisation

Used in several applications:

X-ray spectroscopy, α -spectroscopy, neutron detection

Ideal for Rare Event searches!

CHECK OUT

🕒 I.Manthos, Neutron spectroscopy with SPCs
Tue April 5th, 11:00 am

🕒 P. Knights, R2D2 $0\nu\beta\beta$ Experiment
Wed April 6th, 11:15 am

I.Giomataris et al, JINST, 2008, P09007
I.Katsioulas et al, JINST, 13, 2018, P11006

New Experiments With Spheres - Gas



► NEWS-G Collaboration

► 5 countries

► 10 institutes

► ~40 collaborators

► Three underground laboratories

► SNOLAB

► Laboratoire Souterrain de Modane

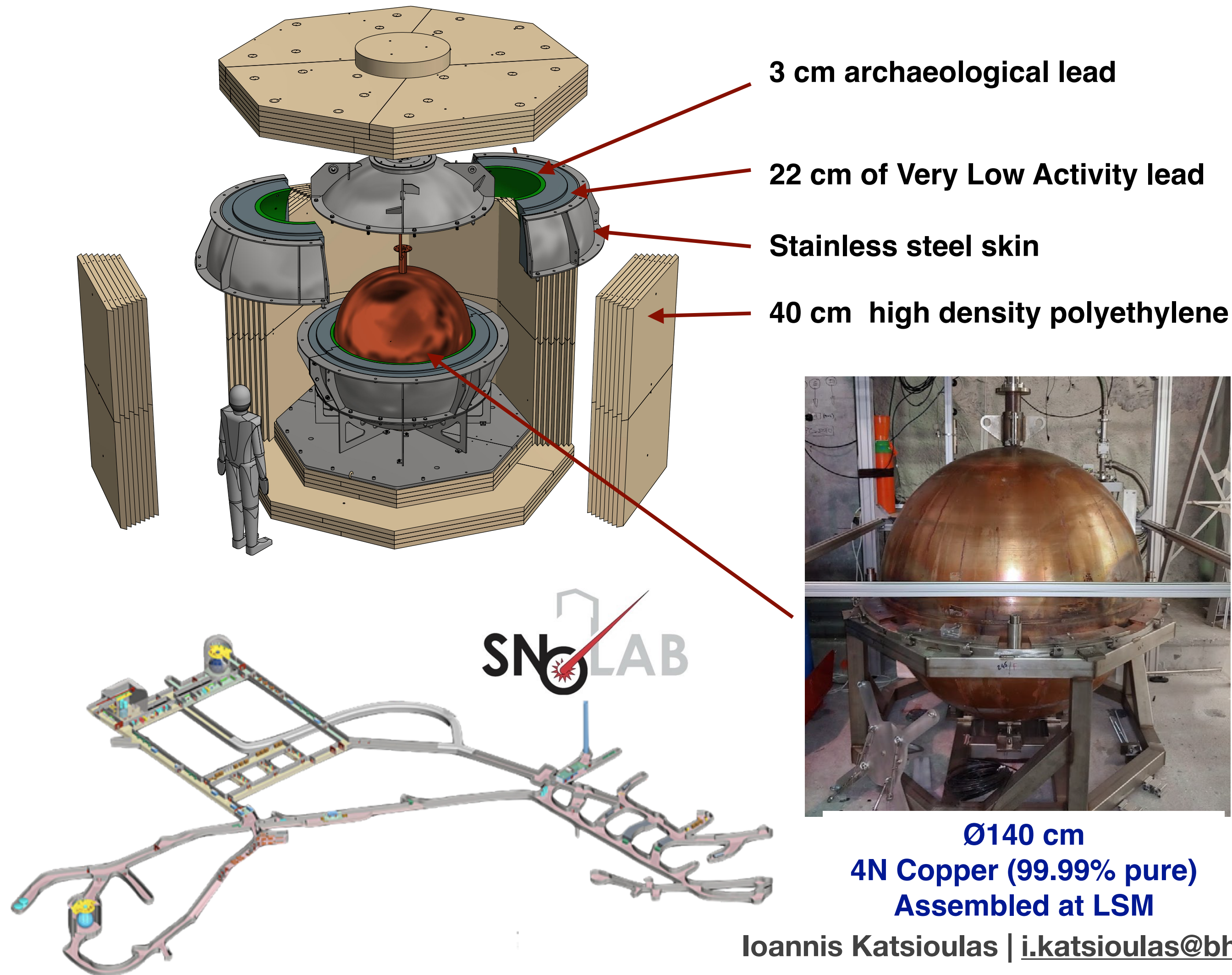
► Boulby Underground Laboratory

Light dark matter searches with
Spherical Proportional Counters!

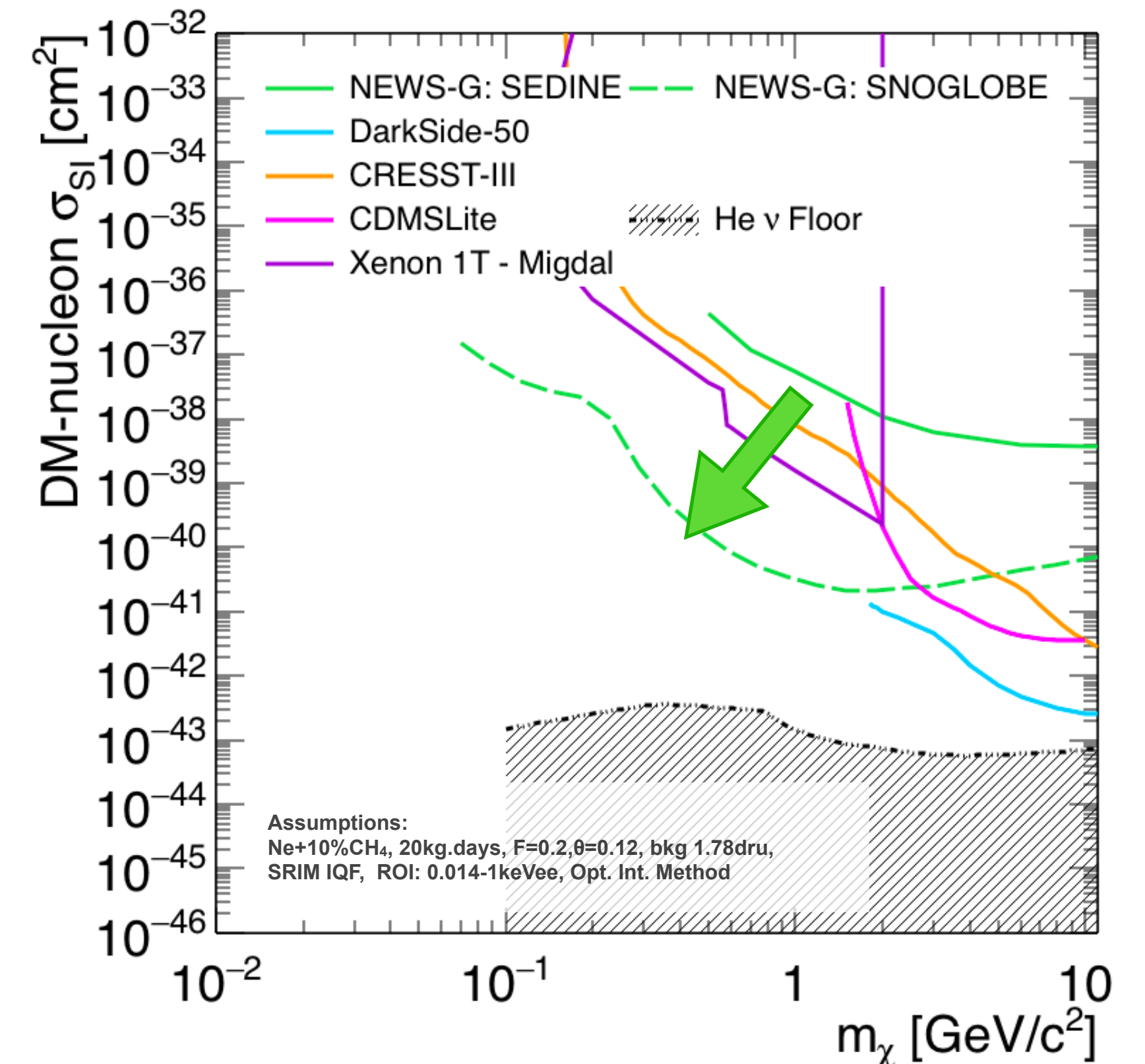


NEWS-G at SNOLAB

The SNOGLOBE detector



- First NEWS-G results obtained with SEDINE
Ø60 cm detector installed at Modane
[Astropart. Phys. 97, 54 (2018)]
- Ø140 cm detector installed at SNOLAB
 - Detector commissioning on-going
 - Physics data-taking to follow



High Purity Copper

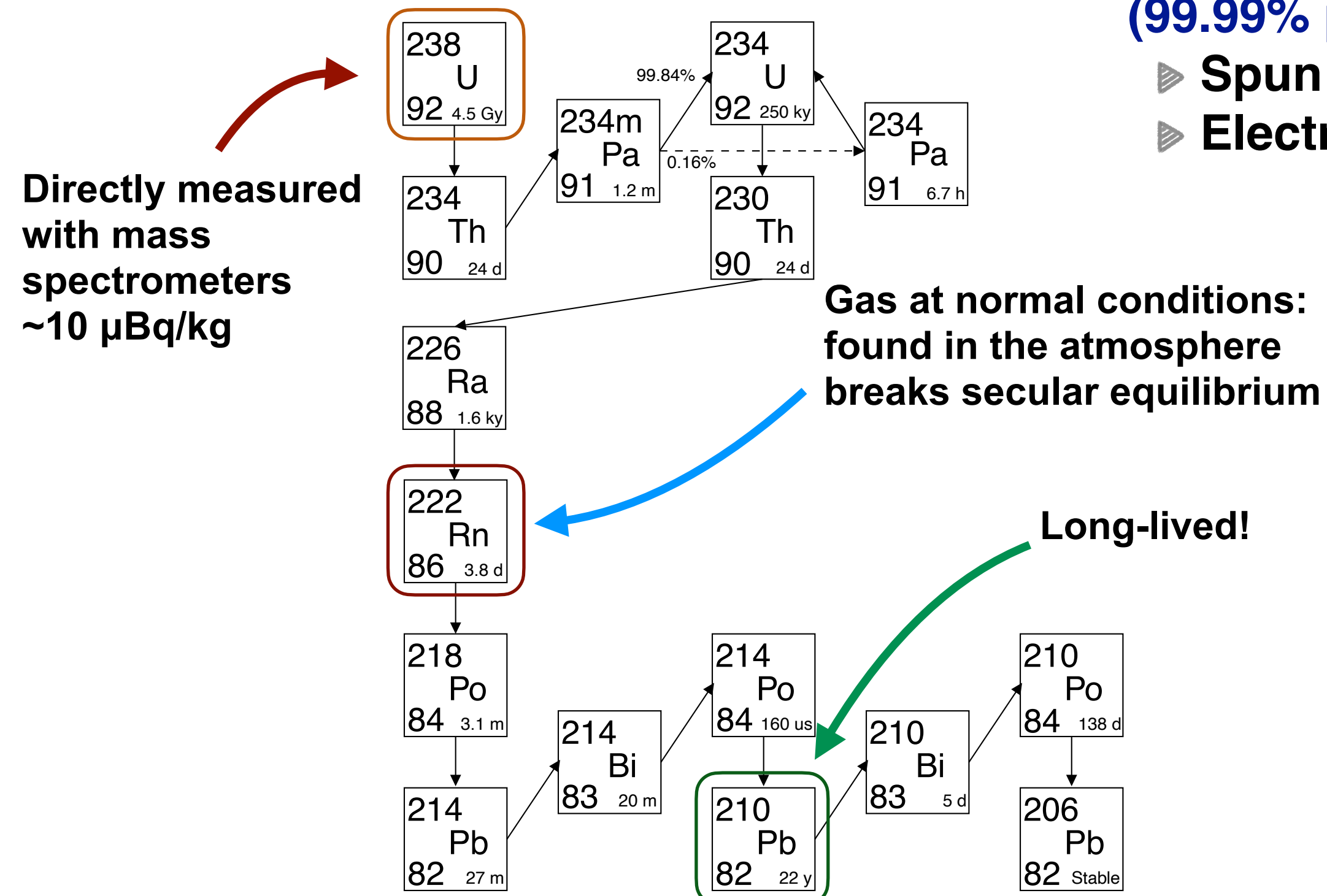
An ideal material for low radioactivity construction

- **Copper common material for rare event experiments**

- ▶ Strong, pure, inexpensive
- ▶ No long-lived isotopes (^{67}Cu $t_{1/2}=62\text{h}$)

- **Backgrounds**

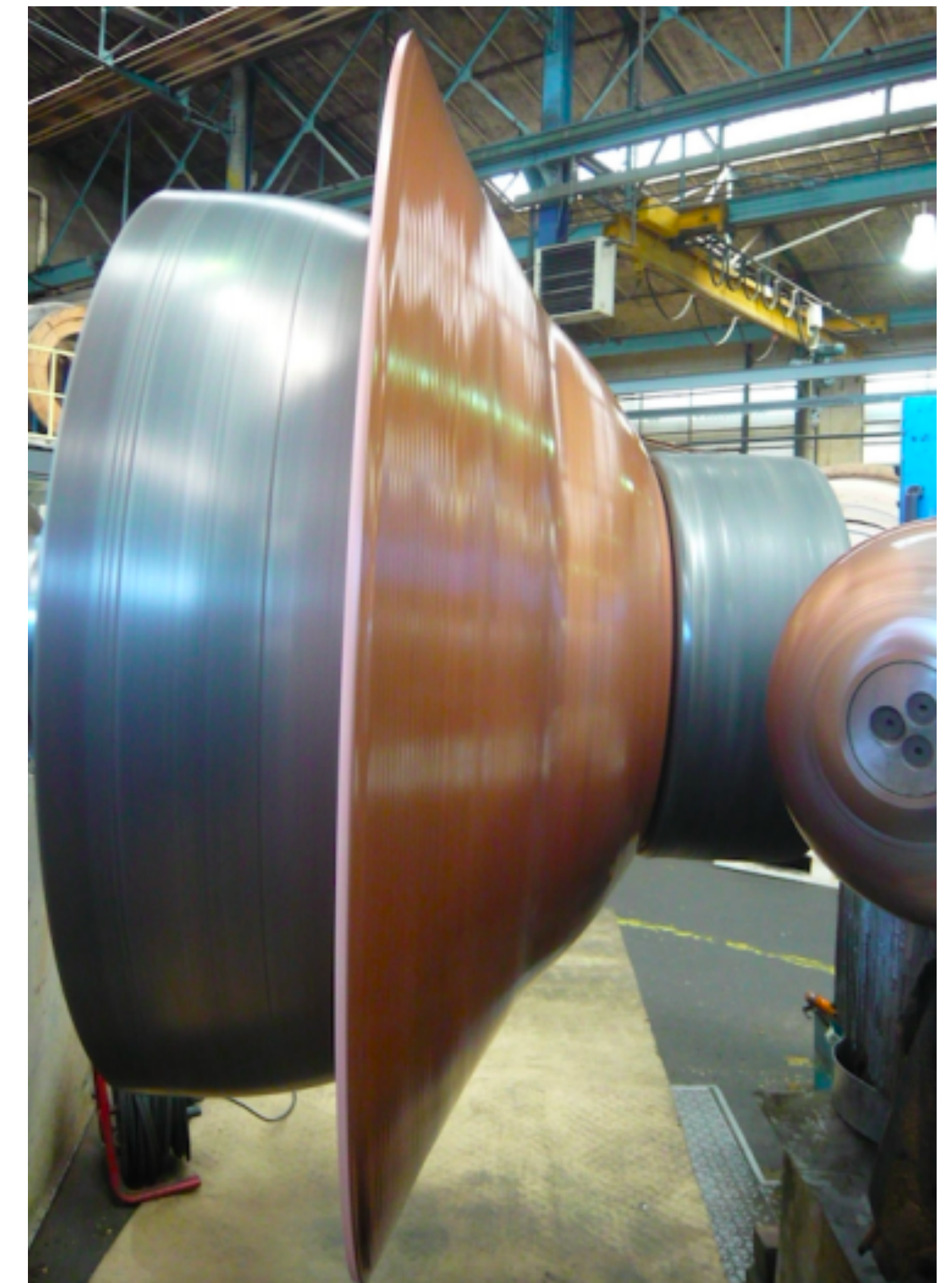
- ▶ Cosmogenic and $^{238}\text{U}/^{232}\text{Th}$ decay chain



Ø 140cm detector at SNOLAB

4N Aurubis AG Oxygen Free Copper
(99.99% pure)

- ▶ Spun into two hemispheres
- ▶ Electron-beam welded together



Copper contamination - Background

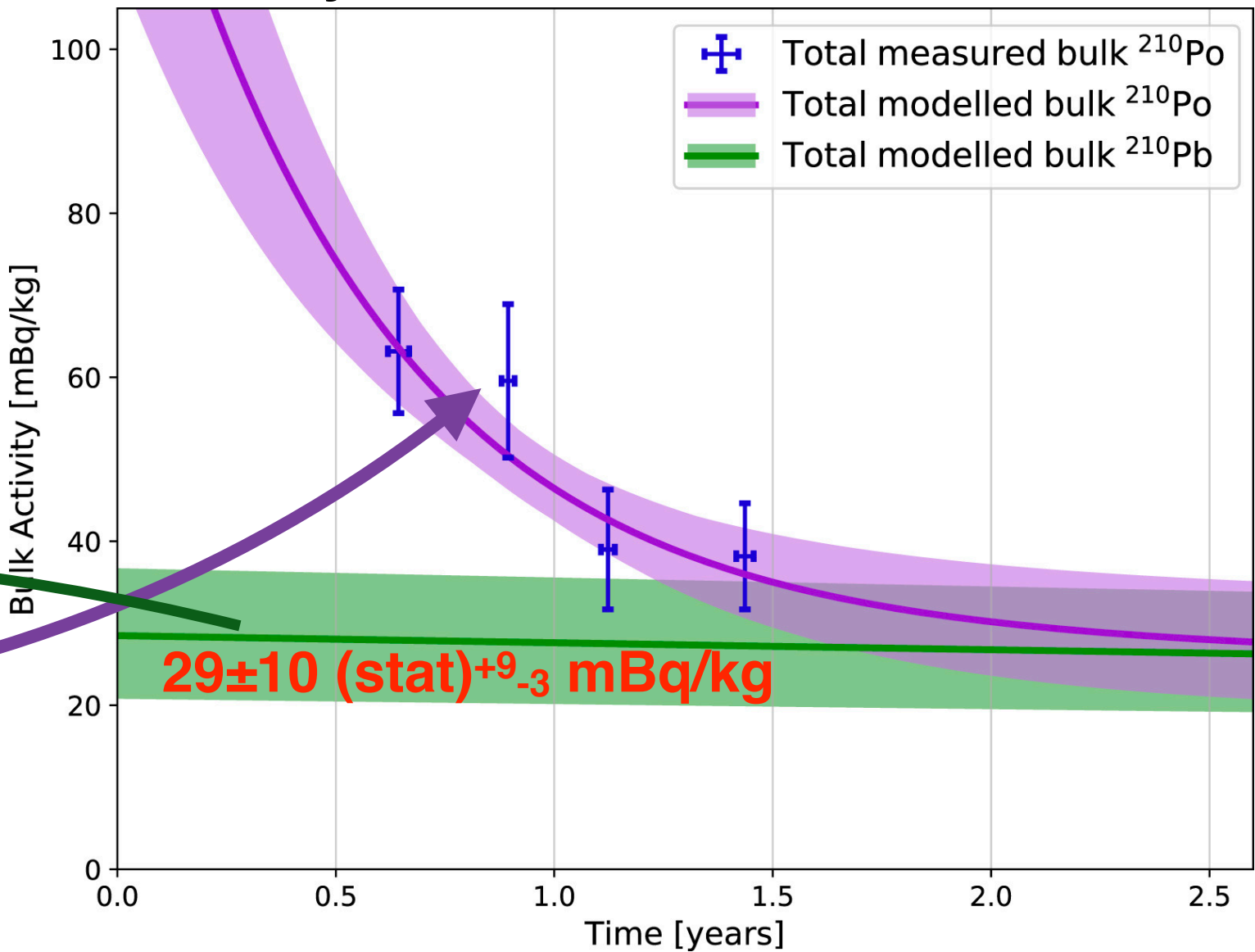
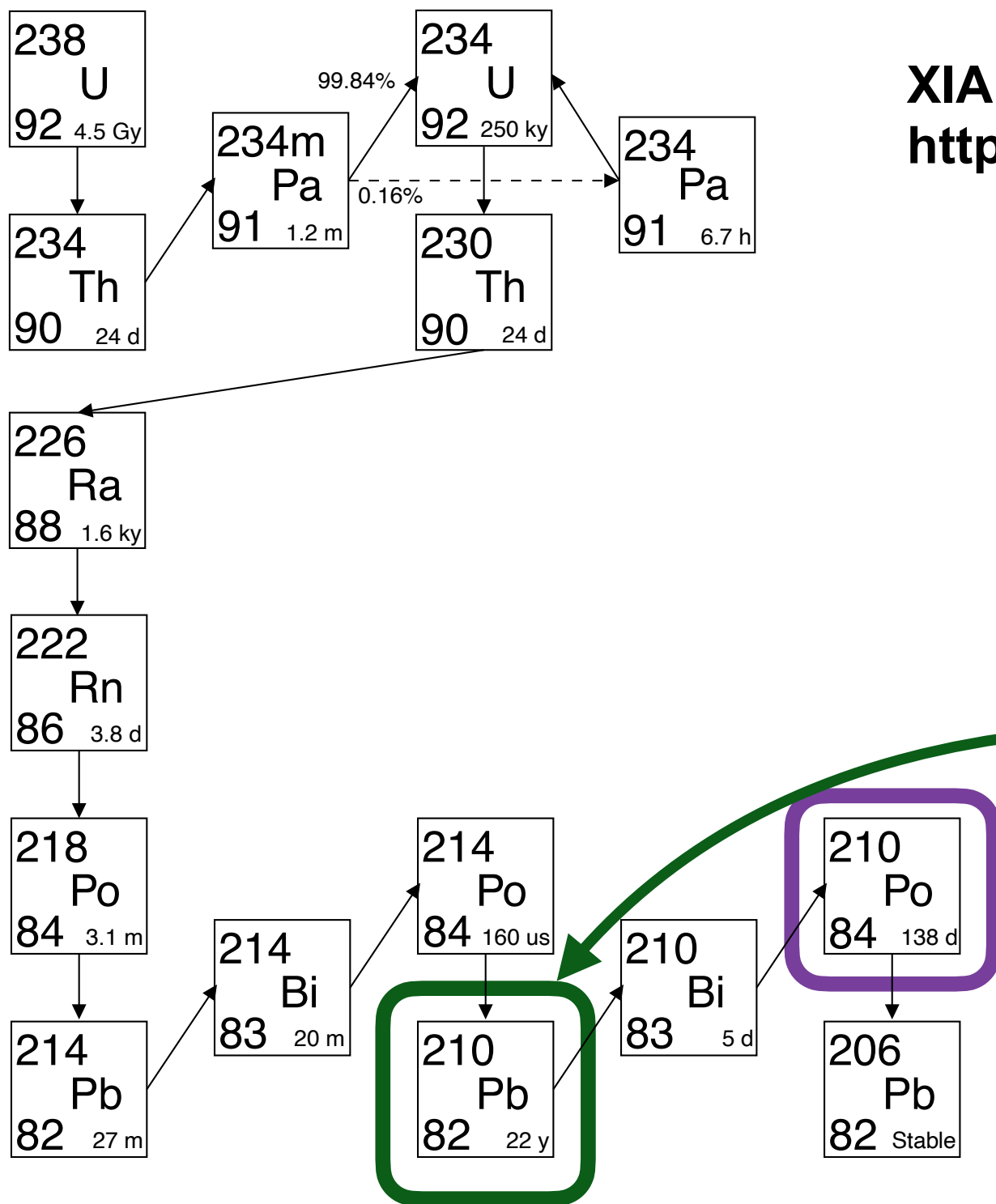
Backgrounds from Rn and its progenies

Estimation of out-of-equilibrium ^{210}Pb contamination through low background α -particle counting

- Radioassay for NEWS-G showed:
 - ▶ ~10 $\mu\text{Bq/kg}$ using ICP-MS from ^{238}U and ^{232}Th
 - ▶ ~28.5 mBq/kg from out of equilibrium ^{210}Pb using XIA UltraLo by inferring progeny activities



XIA UltraLo-1800
<https://www.xia.com/ultral0-theory.html>



NIM A 988 (2021) 164844

Underground electroplated copper

Shielding against Rn-chain induced radiation

SNOLAB detector: 4N Aurubis AG Oxygen Free Cu (99.99% pure)

► Out-of-equilibrium ^{210}Pb contamination: 29 ± 10 (stat) $^{+9}_{-3}$ mBq/kg

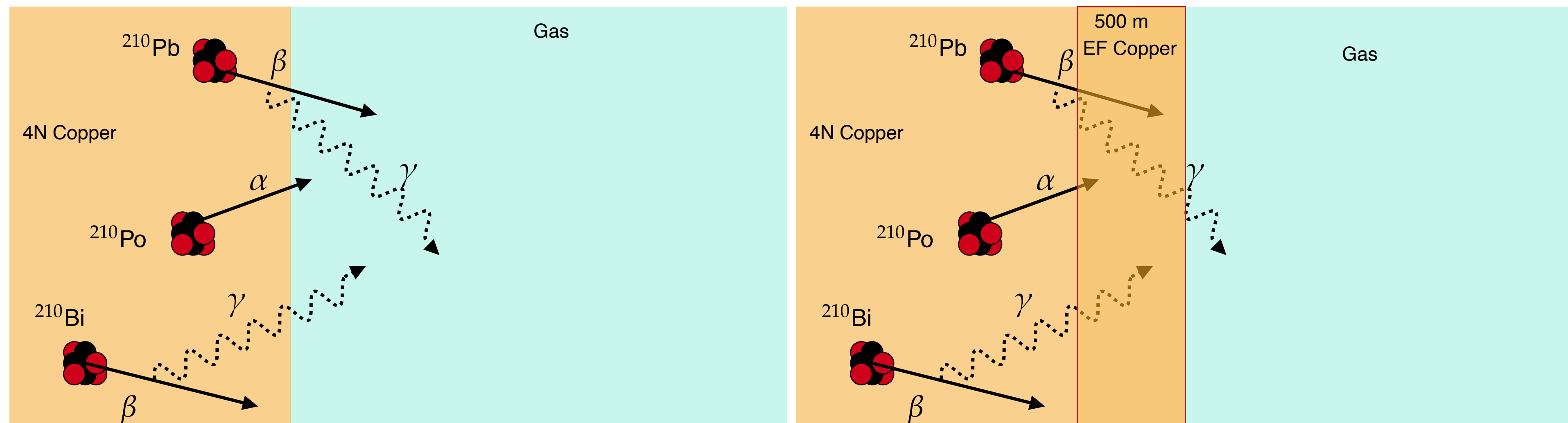
Background

► Bremsstrahlung X-rays from ^{210}Pb and ^{210}Bi β -decays in Cu

Internal shield

► Ultra-pure Cu layer on detector inner surface - 500 μm thick

► Suppresses ^{210}Pb and ^{210}Bi backgrounds by factor 2.6 under 1 keV



Underground electroformation at LSM



Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima



Copper electroplating for background suppression in the NEWS-G experiment

L. Balogh ^a, C. Beaufort ^b, A. Brossard ^a, R. Bunker ^c, J.-F. Caron ^a, M. Chapellier ^a, J.-M. Coquillat ^a, E.C. Corcoran ^d, S. Crawford ^a, A. Dastgheibi Fard ^b, Y. Deng ^e, K. Dering ^a, D. Durnford ^e, G. Gerbier ^a, I. Giomataris ^f, G. Giroux ^a, P. Gorel ^{g,h,i}, M. Gros ^f, P. Gros ^a, O. Guillaudin ^b, E.W. Hoppe ^c, I. Katsioulas ^j, F. Kelly ^d, P. Knights ^{f,j,*}, L. Kwon ^d, S. Langrock ^h, P. Lautridou ^k, R.D. Martin ^a, J.-P. Mols ^l, J.-F. Muraz ^b, X.-F. Navick ^f, T. Neep ^j, K. Nikolopoulos ^j, P. O'Brien ^e, R. Owen ^j, M.-C. Piro ^e, D. Santos ^b, G. Savvidis ^a, I. Savvidis ^l, F. Vazquez de Sola Fernandez ^a, M. Vidal ^a, R. Ward ^j, M. Zampaolo ^b

(NEWS-G Collaboration)

S. Alcantar Anguiano ^c, I.J. Arnquist ^c, M.L. di Vacri ^c, K. Harouaka ^c, K. Kobayashi ^{m,n,1}, K.S. Thommasson ^c

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^h SNOLAB, Lively, Ontario, P3Y 1N2, Canada

ⁱ Arthur B. McDonald Canadian Astroparticle Physics Research Institute, Queen's University, Kingston, ON, K7L 3N6, Canada

^j School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

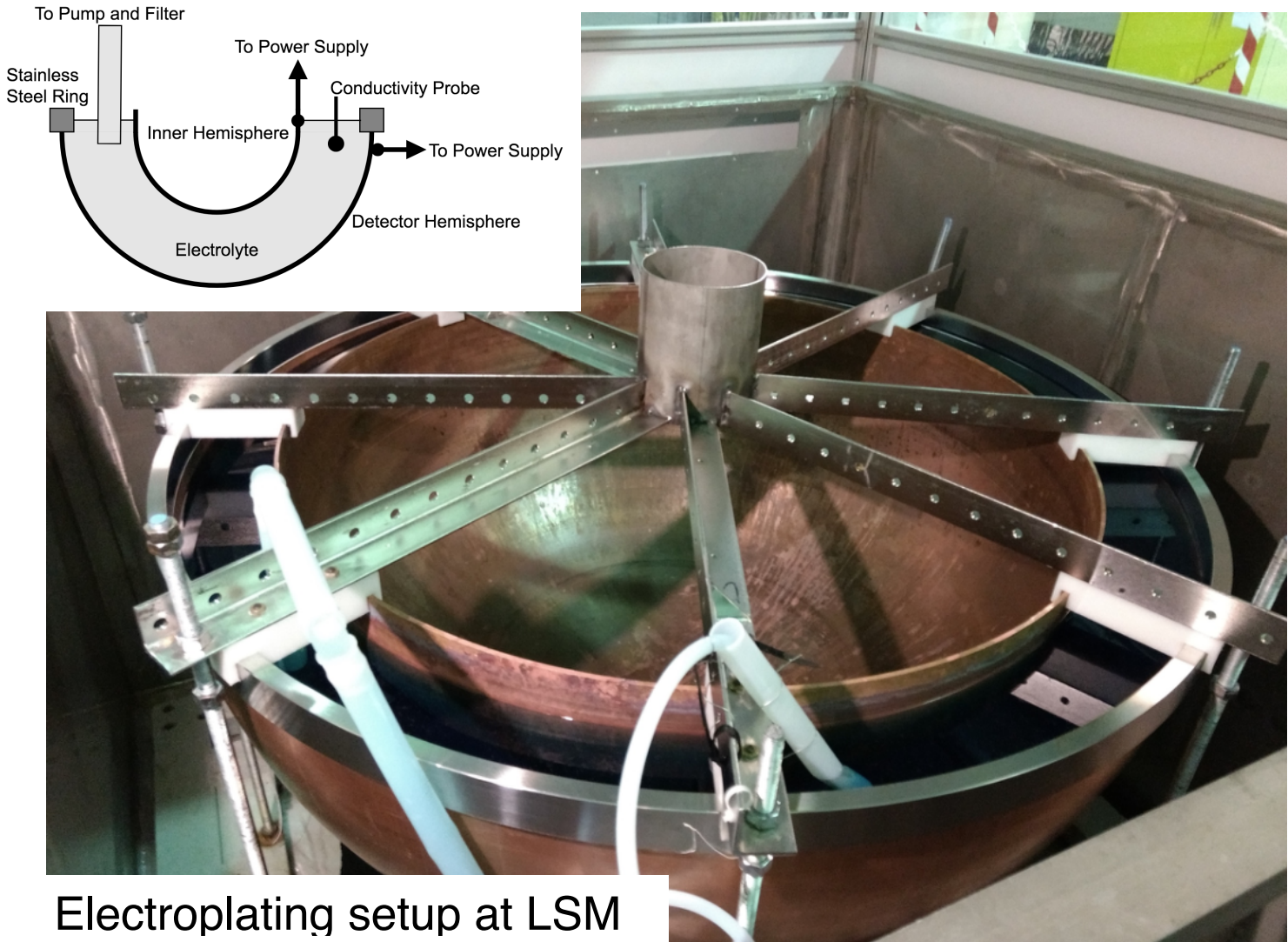
^k SUBATECH, IMT-Atlantique, Université de Nantes/IN2P3-CNRS, Nantes, France

^l Aristotle University of Thessaloniki, Thessaloniki, Greece

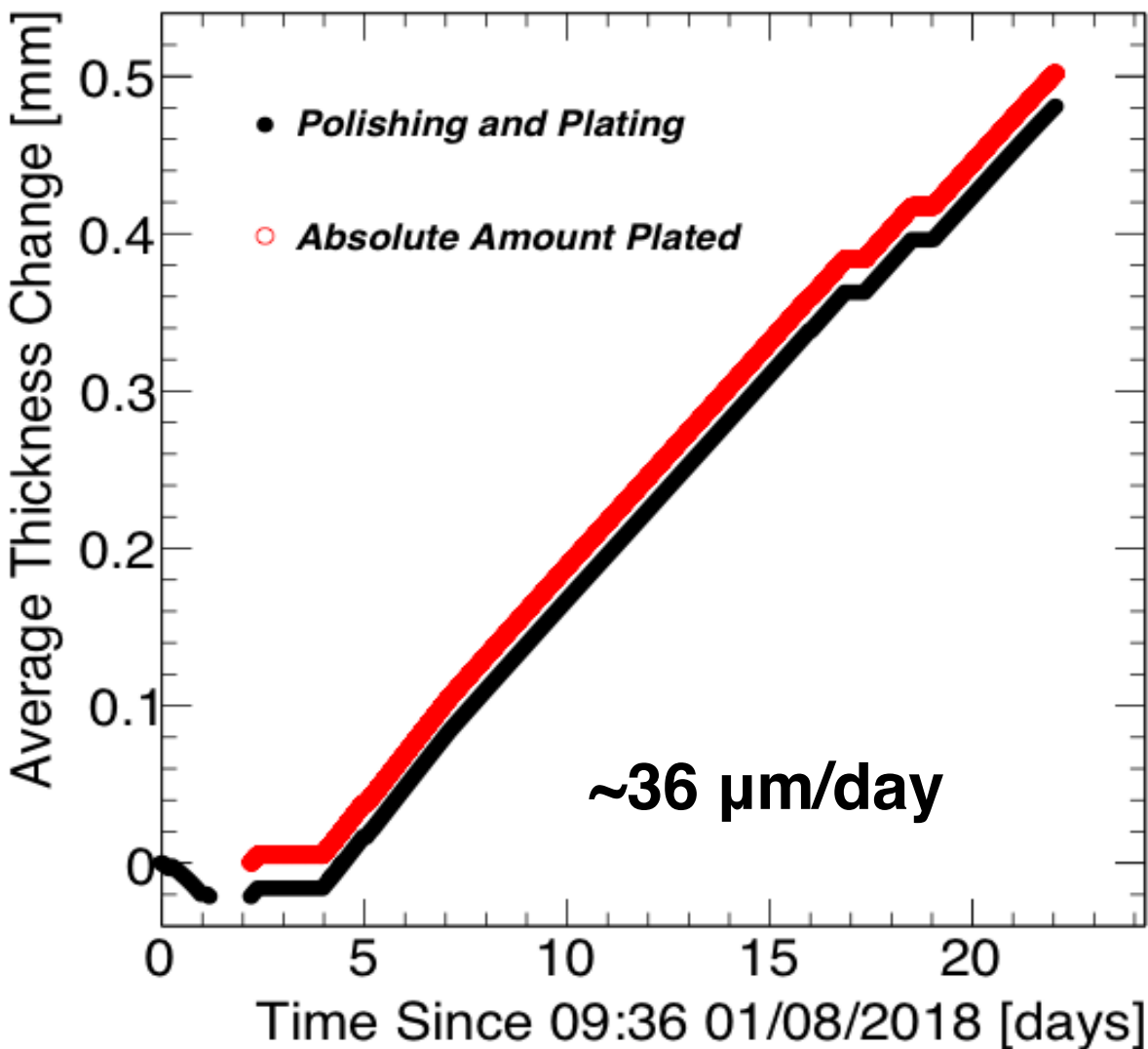
^m Kamioka Observatory, ICRR, University of Tokyo, Higashi-Mozumi, Kamioka, Hida, Gifu 506-1205, Japan

ⁿ Kavli Institute for the Physics and Mathematics of the Universe, University of Tokyo, Kashiwa, Chiba 277-8582, Japan

- **Copper deposition rate ~1 mm/month!**
- **Potential for fully electroformed detector**
- **Electroformed copper < 0.1 μBq/kg U**



Electroplating setup at LSM



Plated surface

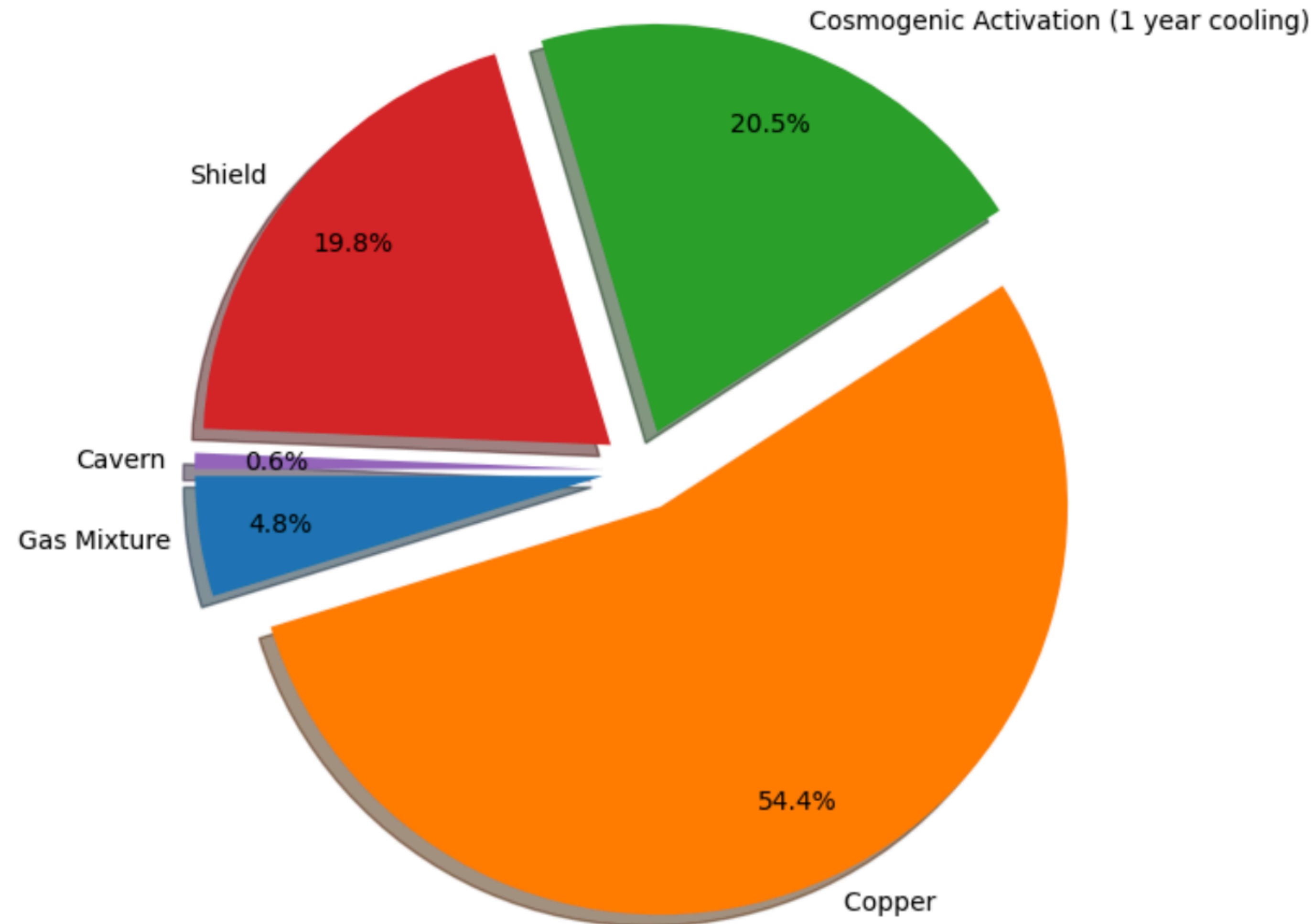


Hemisphere after plating

Sample	Weight [g]	²³² Th [μBq/kg]	²³⁸ U [μBq/kg]
C10100 Cu (Machined)	-	8.7 ± 1.6	27.9 ± 1.9
Cu Electroformed	-	< 0.119	< 0.099
Hemisphere 1	0.256	< 0.58	< 0.26
Hemisphere 2	0.614	< 0.24	< 0.11

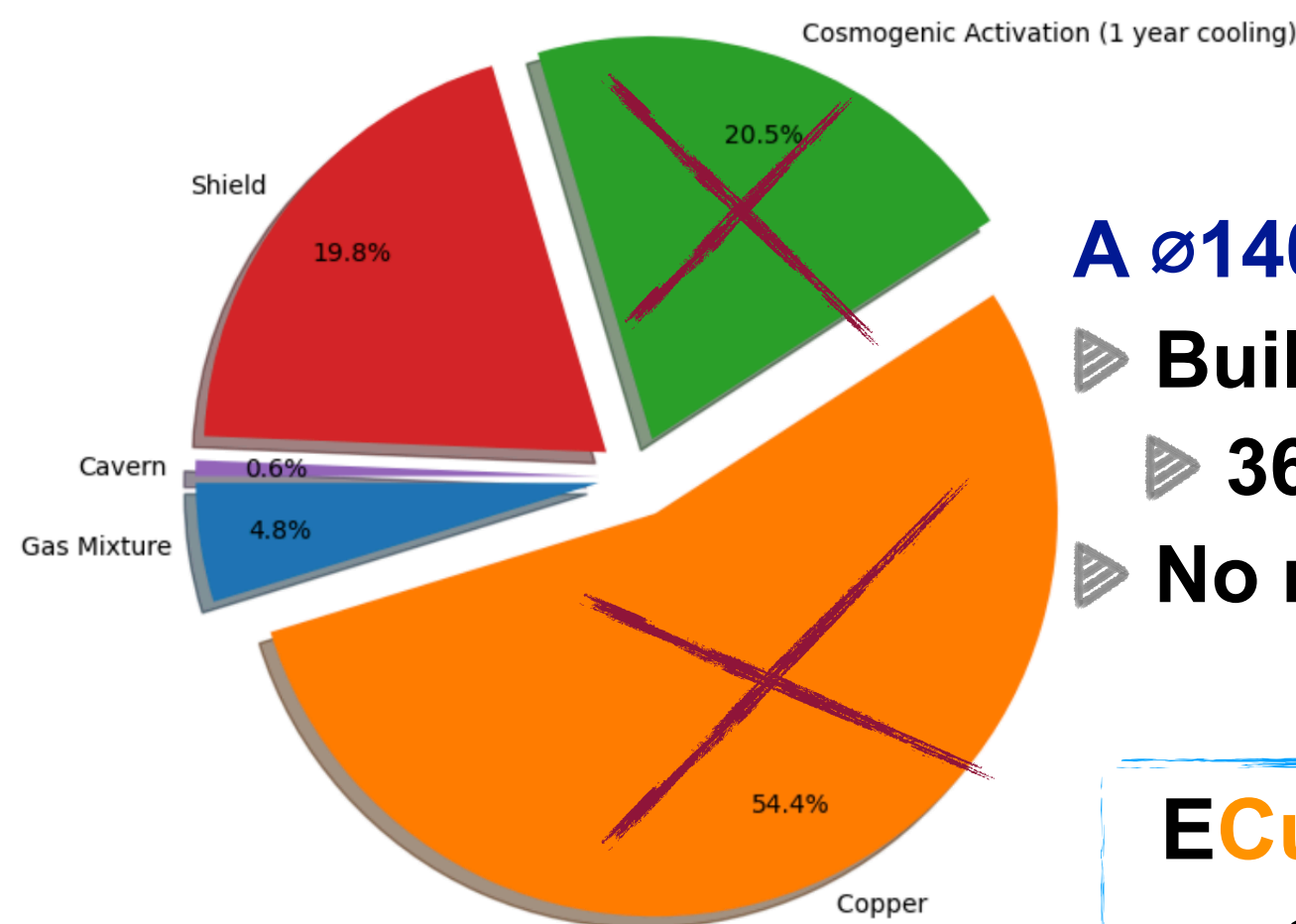
Reducing Backgrounds

SNOGLOBE's current background budget



Electroformed **Cu**prum Manufacturing Experiment

ECuME Fully electroformed underground detectors



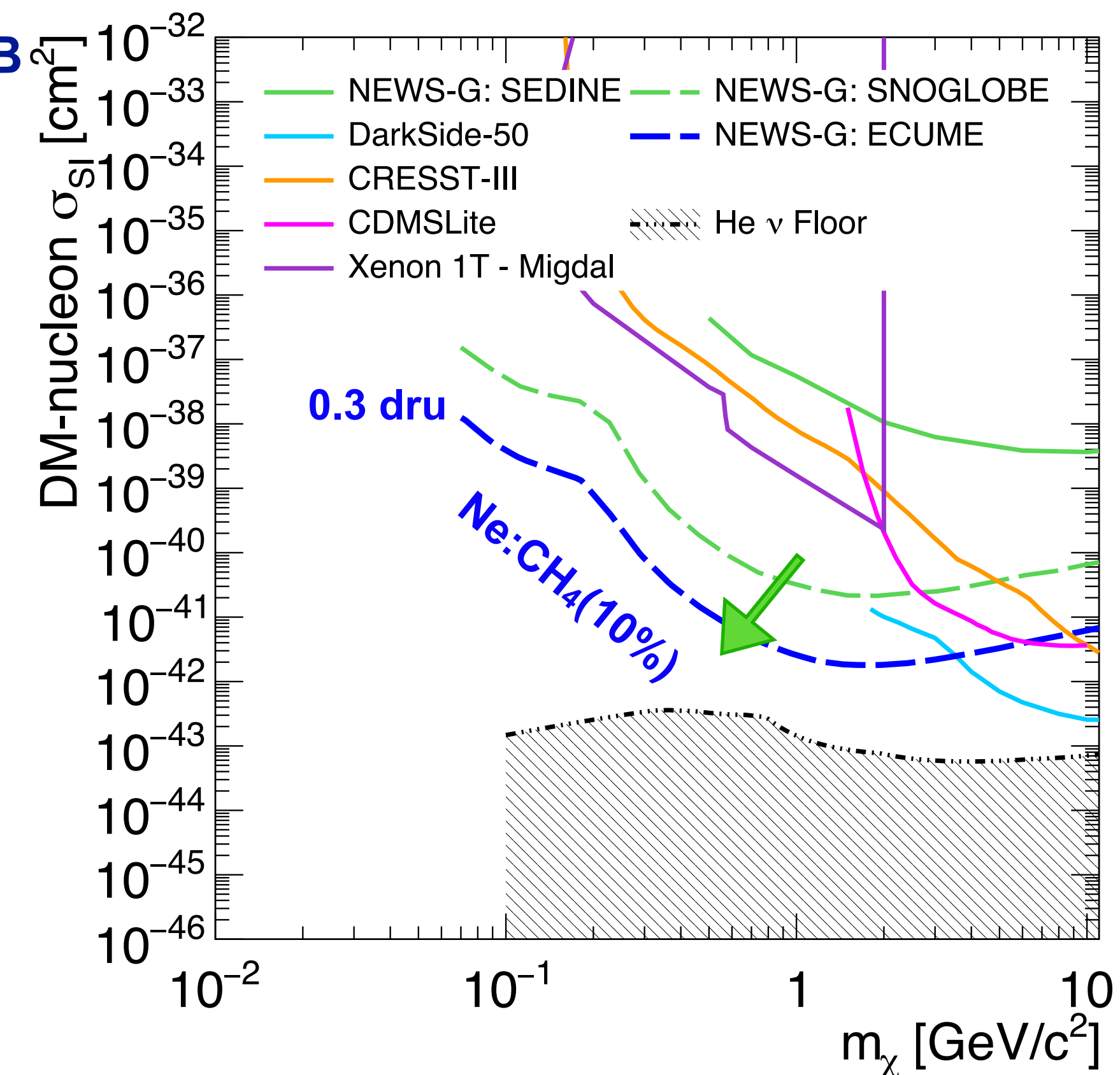
A $\varnothing 140$ cm sphere electroformed underground in SNOLAB

- Builds on NEWS-G achievements on electroplating
- $36 \mu\text{m/day} \rightarrow \sim 1 \text{ mm/month}$
- No machining or welding - fully grown sphere directly

ECuME electroforming facility initially dedicated to NEWS-G, but then a long term asset for SNOLAB and the community

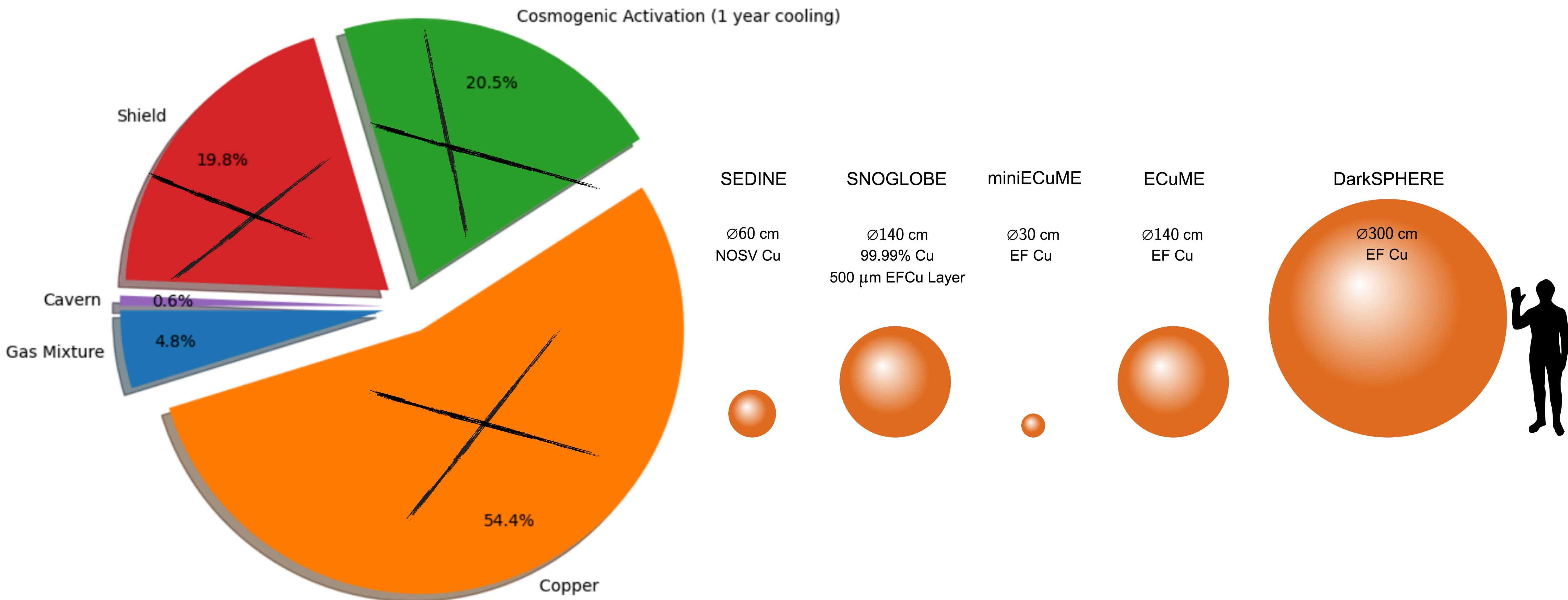
Current Status

- $\varnothing 30$ cm scale prototype to be produced at PNNL
- Bath designed
- Procurement of parts underway
- Electroformation to start soon
- $\varnothing 140$ cm detector to follow shortly after
- Use existing shielding for physics exploitation



DarkSPHERE: Detector Design

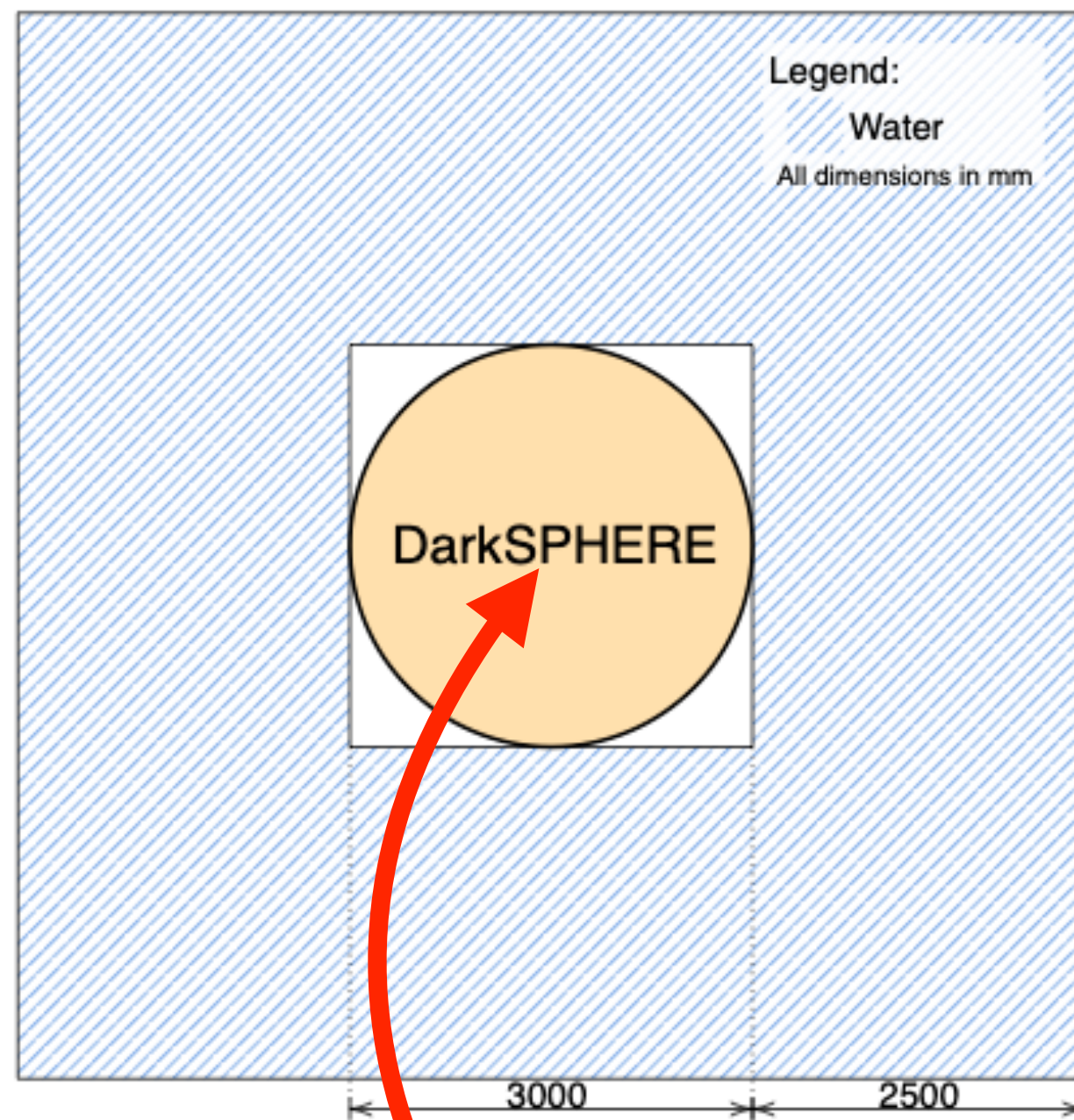
NEWS-G detector evolution



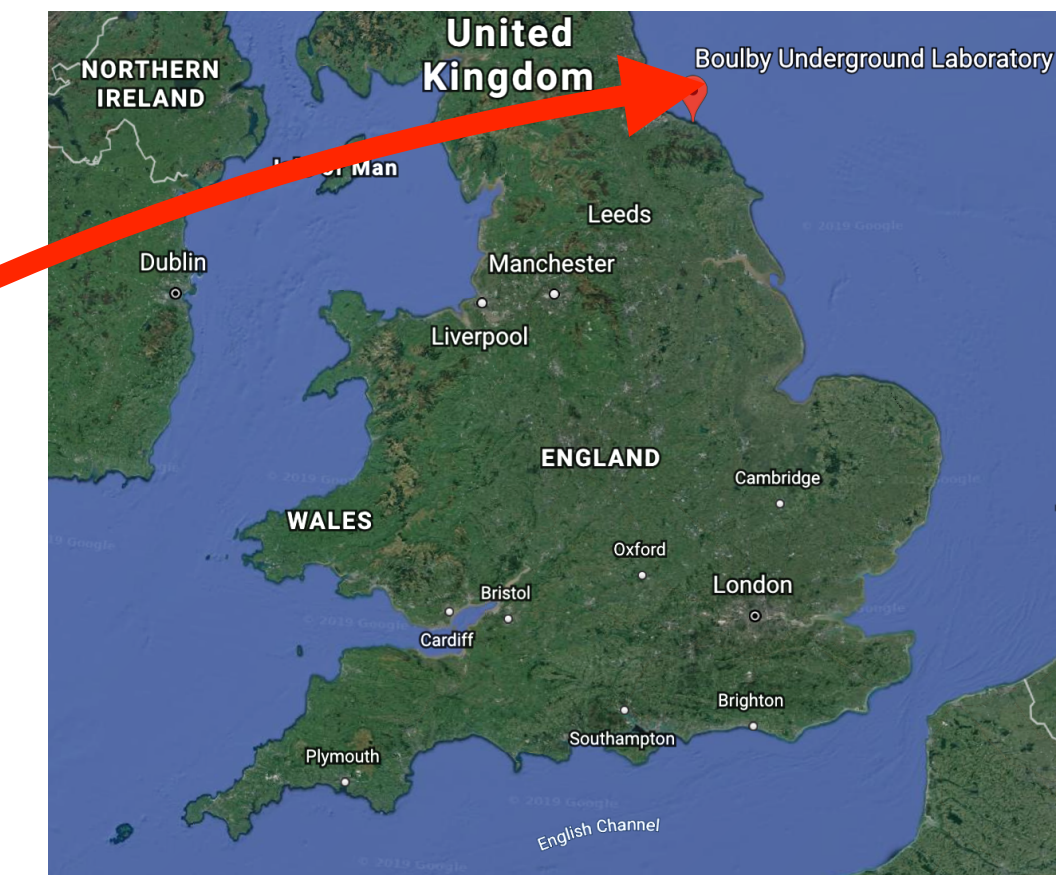
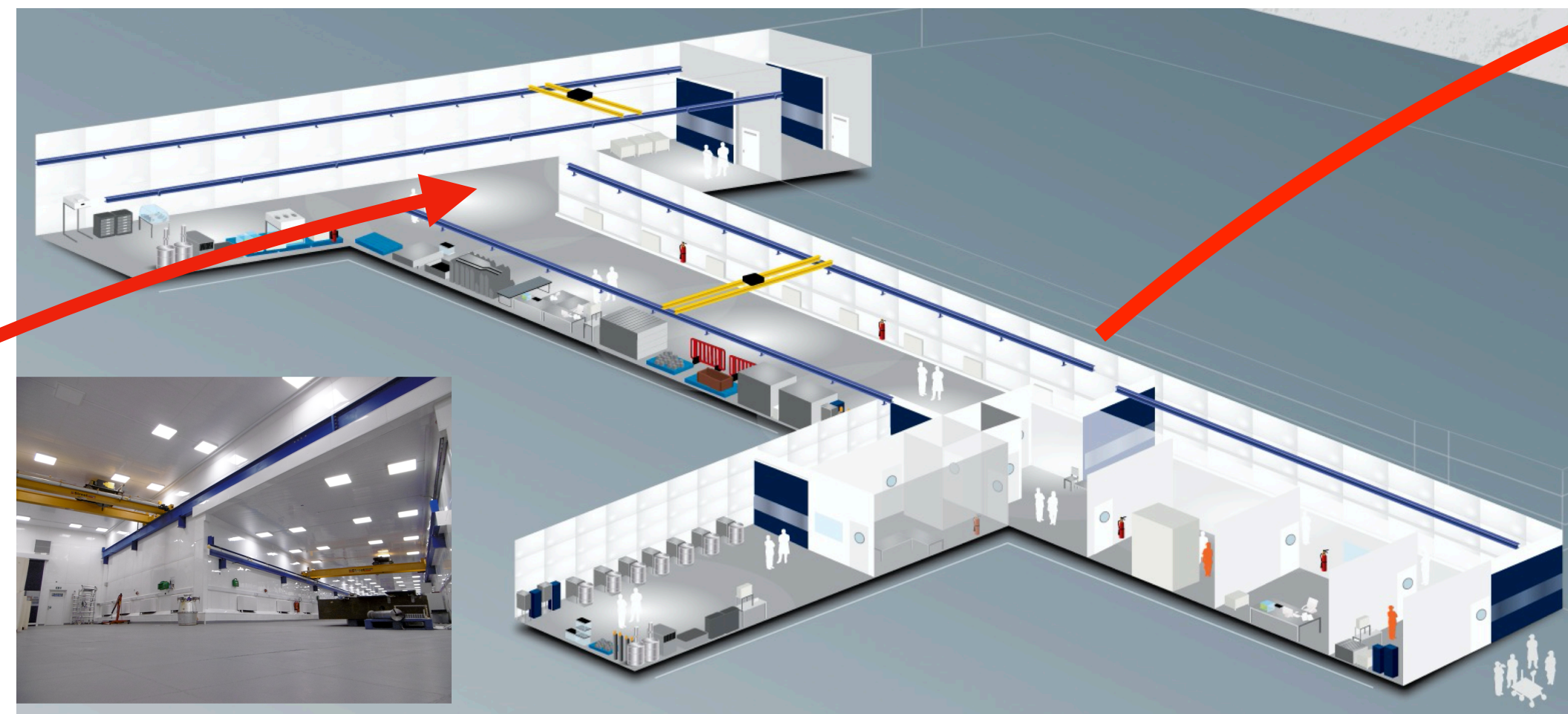
DarkSPHERE: Detector Design

World leading research in North Yorkshire

- $\varnothing 300\text{cm}$ intact underground electroformed SPC
 - ▶ Volume $\times 10$
- Full water shielding
 - ▶ BG 0.01dru ($< 1\text{ keV}$)



5 bar He:C₄H₁₀ (90%:10%)
(27 kg target mass)



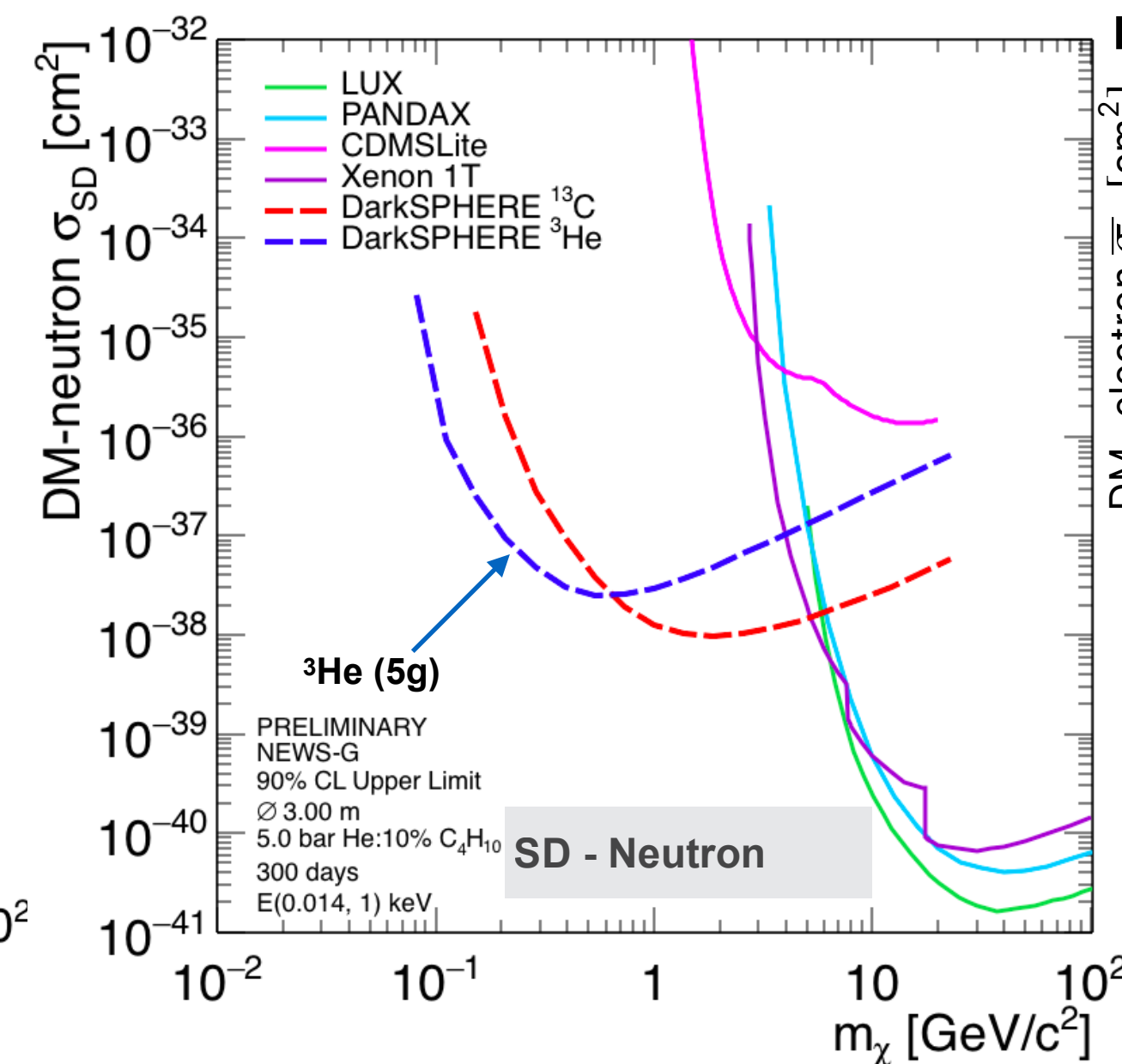
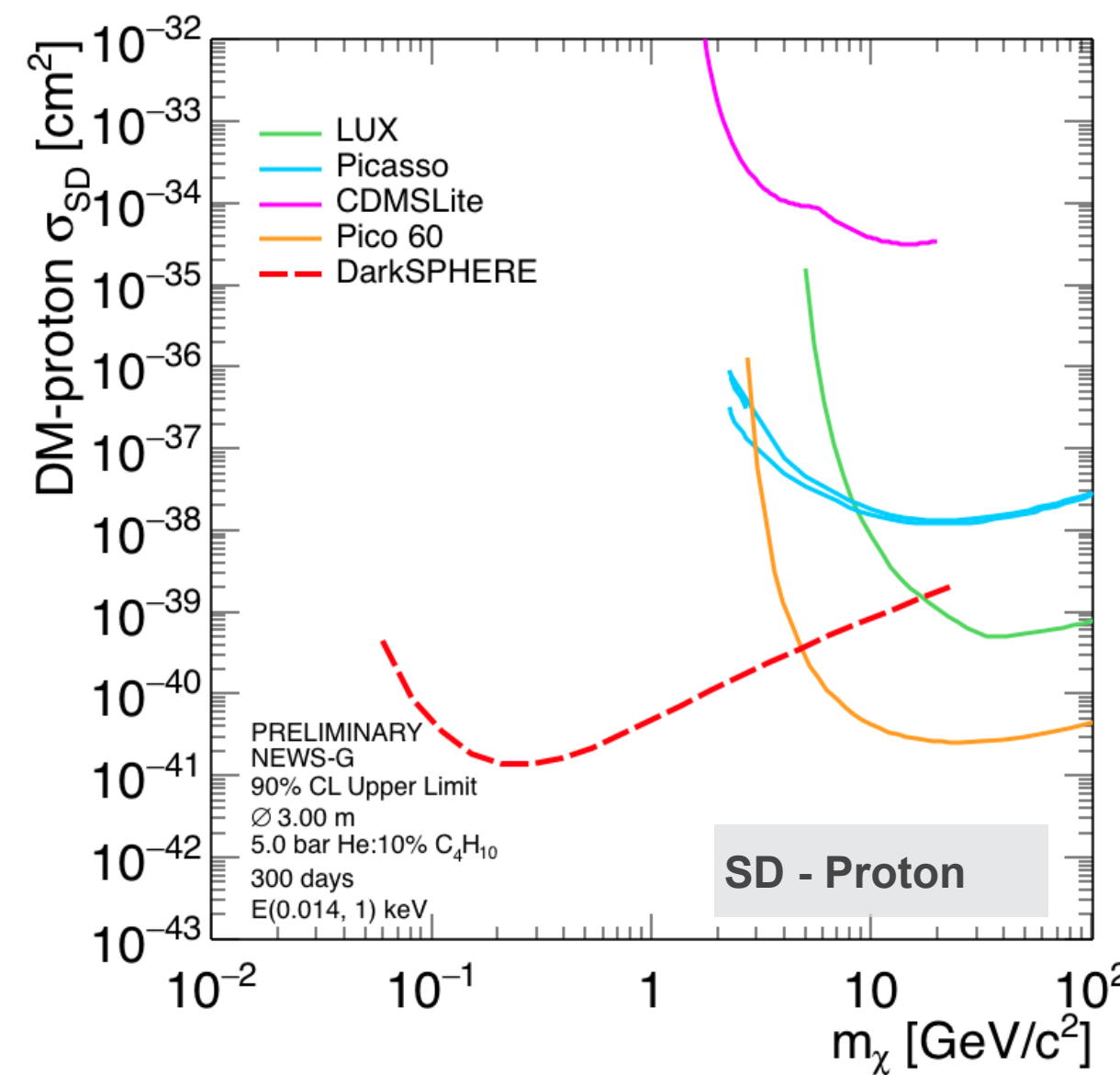
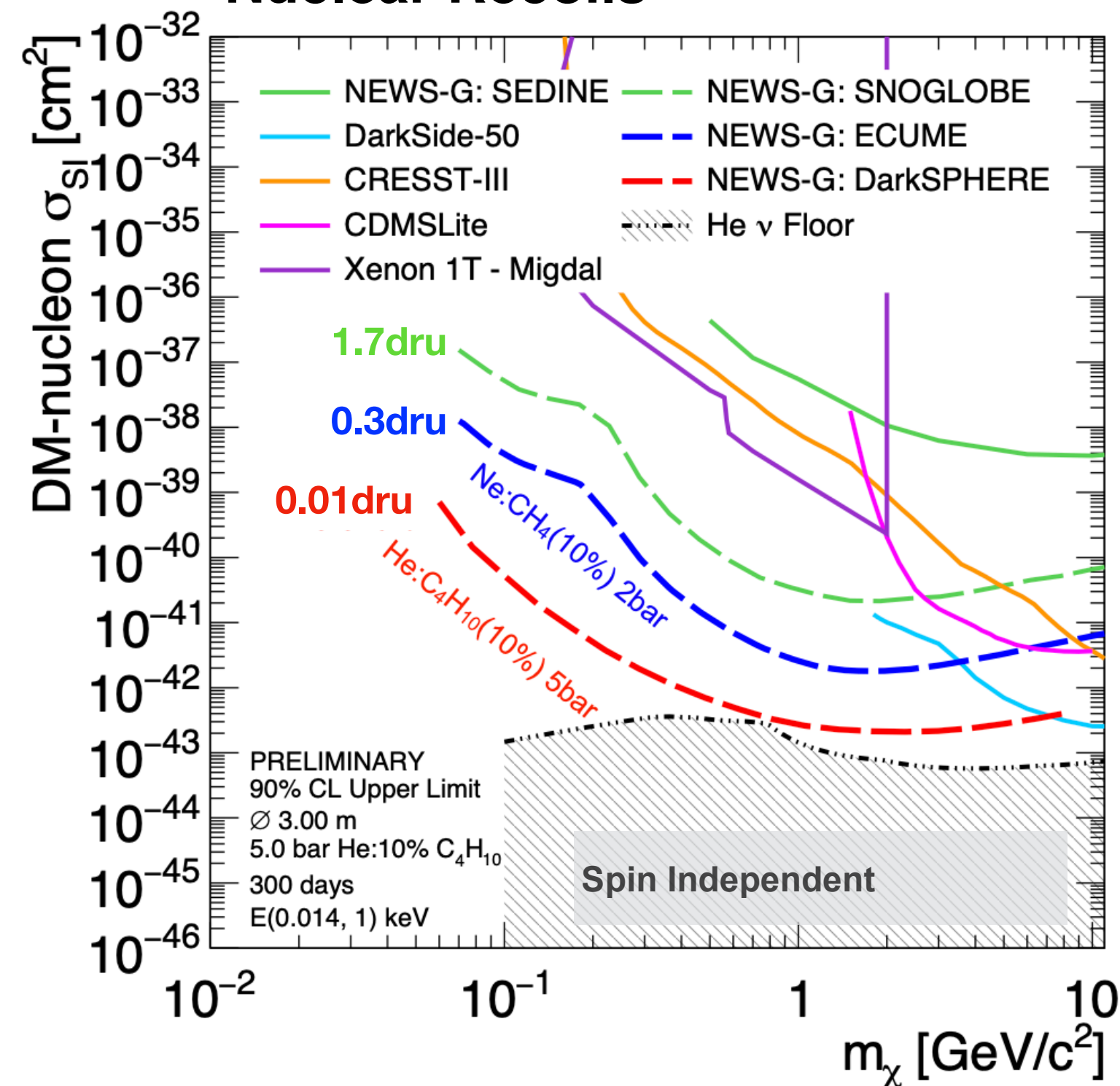
Possibility to host DarkSPHERE at Boulby's Large Experimental Cavern

- ▶ Possibility for a $7\times 7\times 7\text{m}^3$ detector without further excavations
- ▶ Funding obtained for setting-up electroformation facility

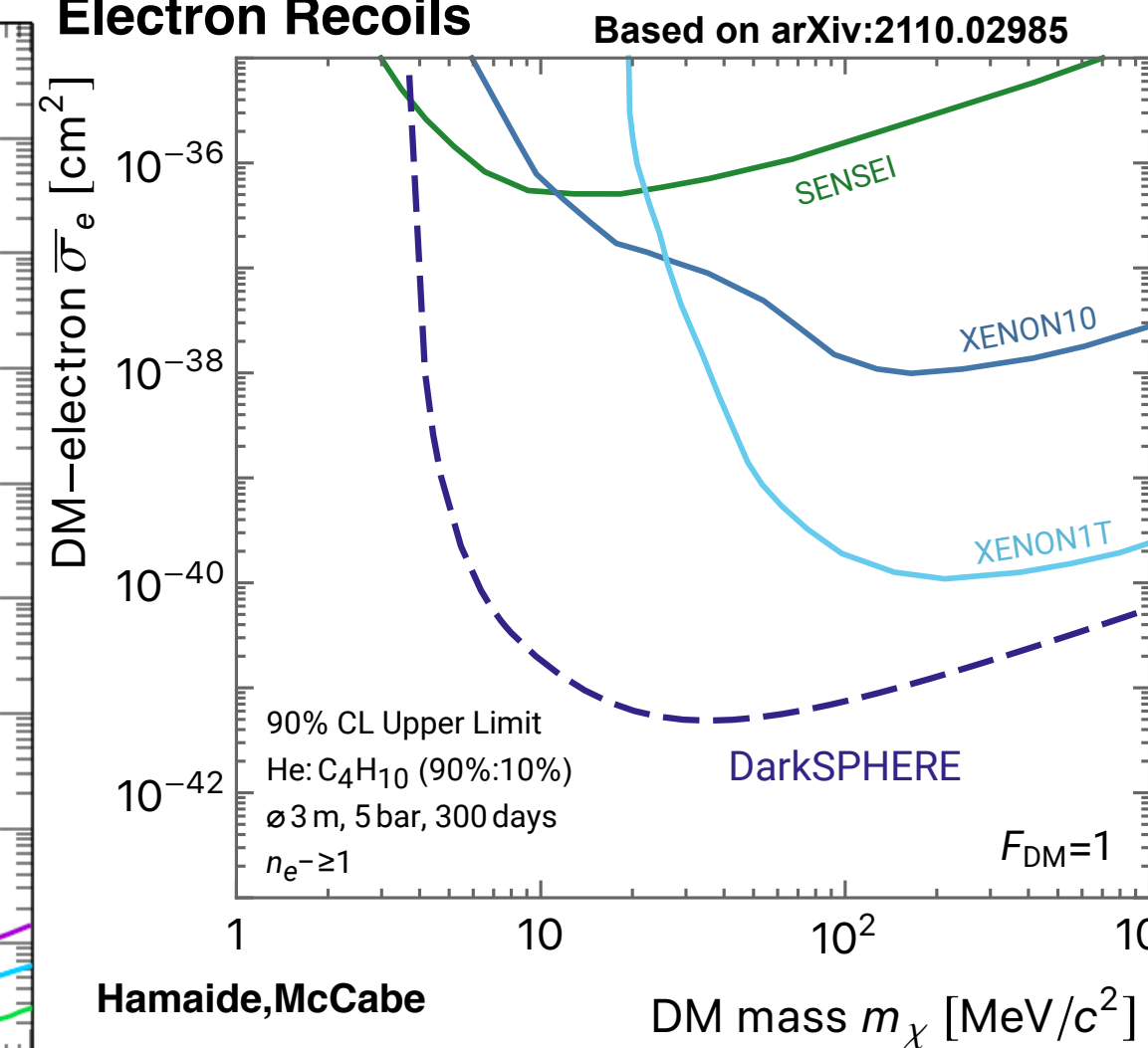
DarkSPHERE: Physics Potential

Unprecedented sensitivity in light WIMPs searches

Nuclear Recoils



Electron Recoils



DarkSPHERE has the potential to probe uncharted territory in light Dark Matter searches

- Nuclear recoils: Spin-independent and spin-dependent
- Electron recoils

Beyond DM:

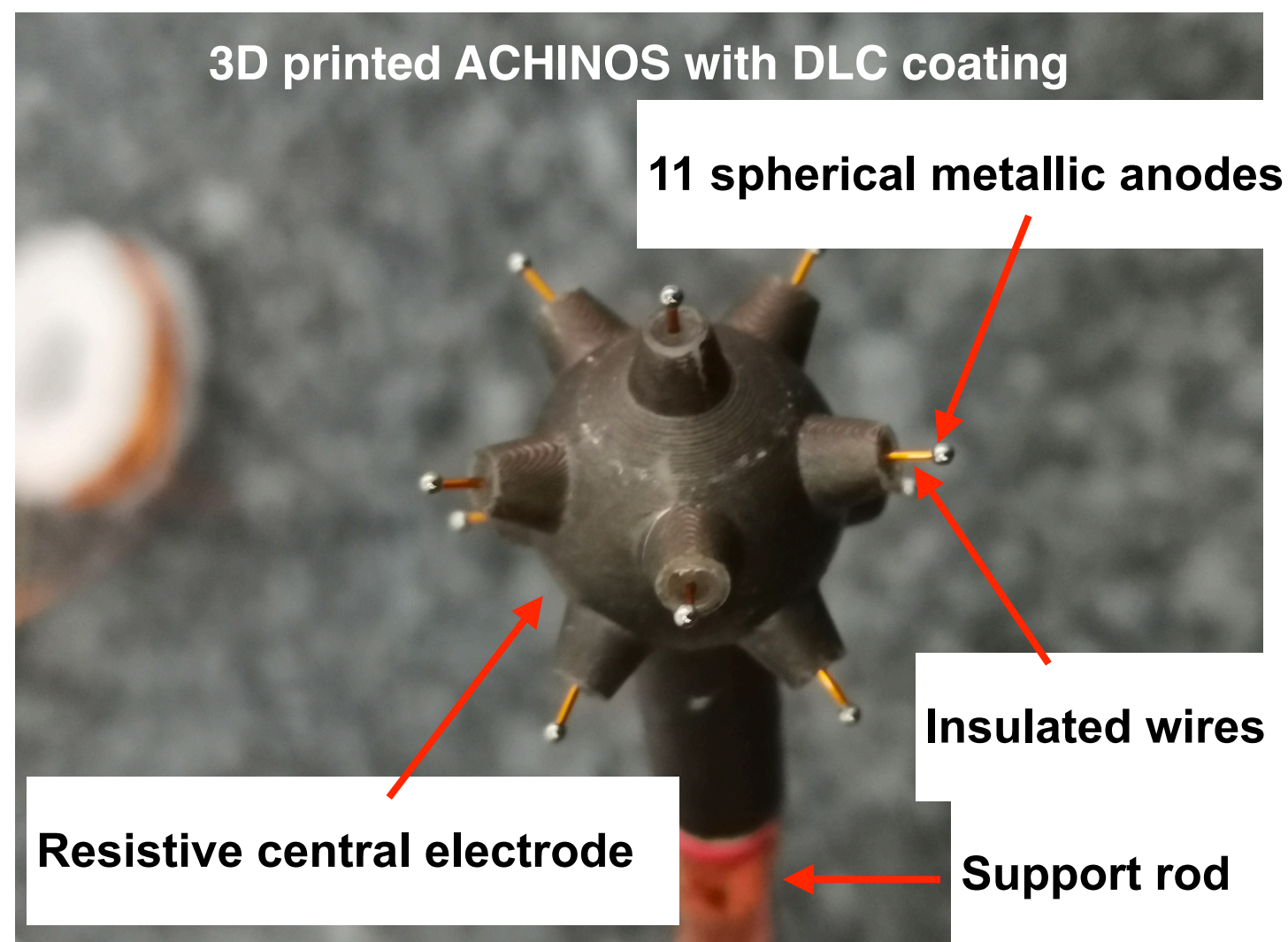
- $0\nu\beta\beta$ searches
- Neutrino physics

Increasing target mass

The multi-anode sensor ACHINOS

Single anode: Drift and Amplification fields are coupled

$$E = \frac{V_a}{r^2} \frac{r_a r_c}{r_c - r_a} \approx \frac{V_a r_a}{r^2}$$

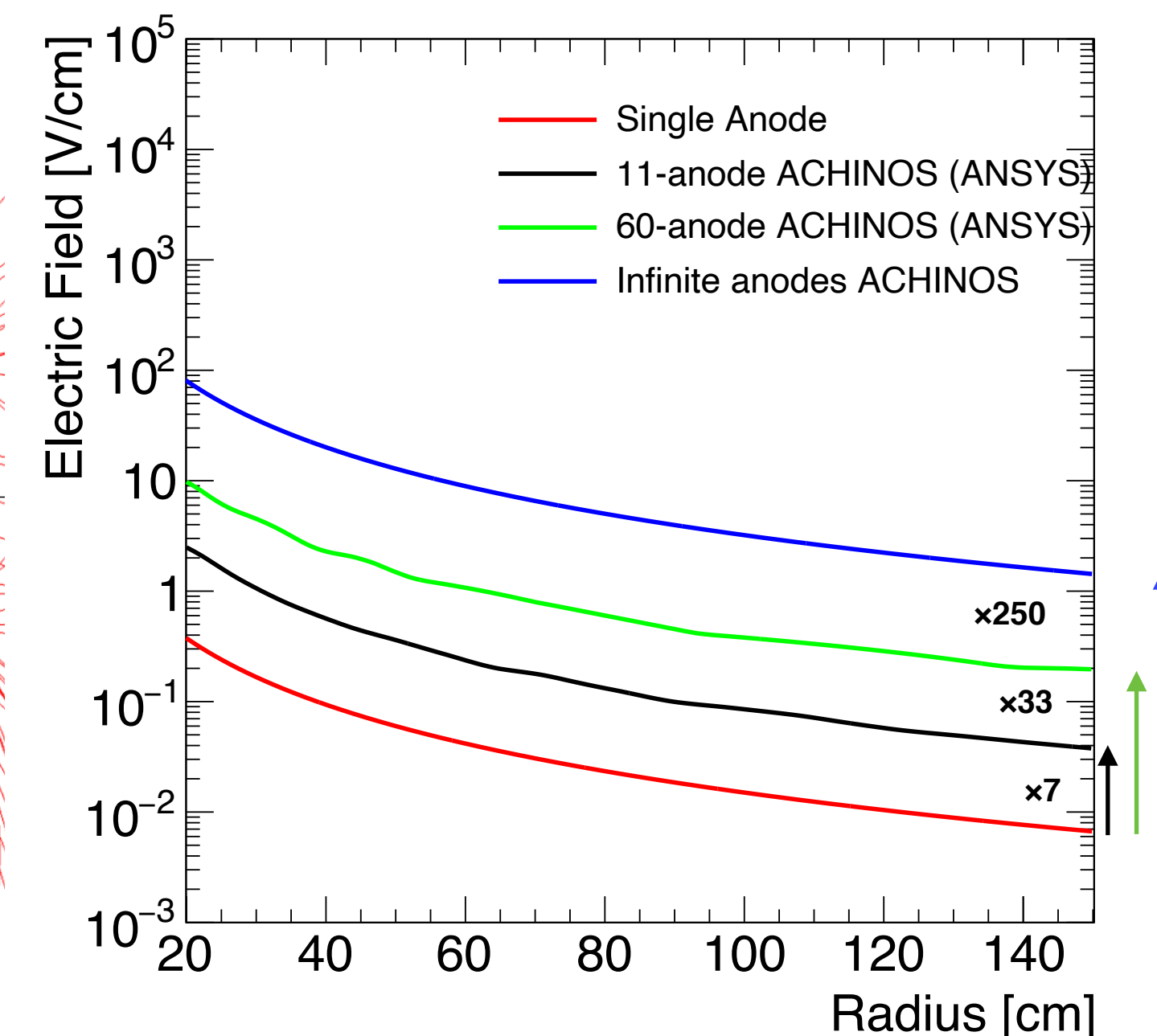
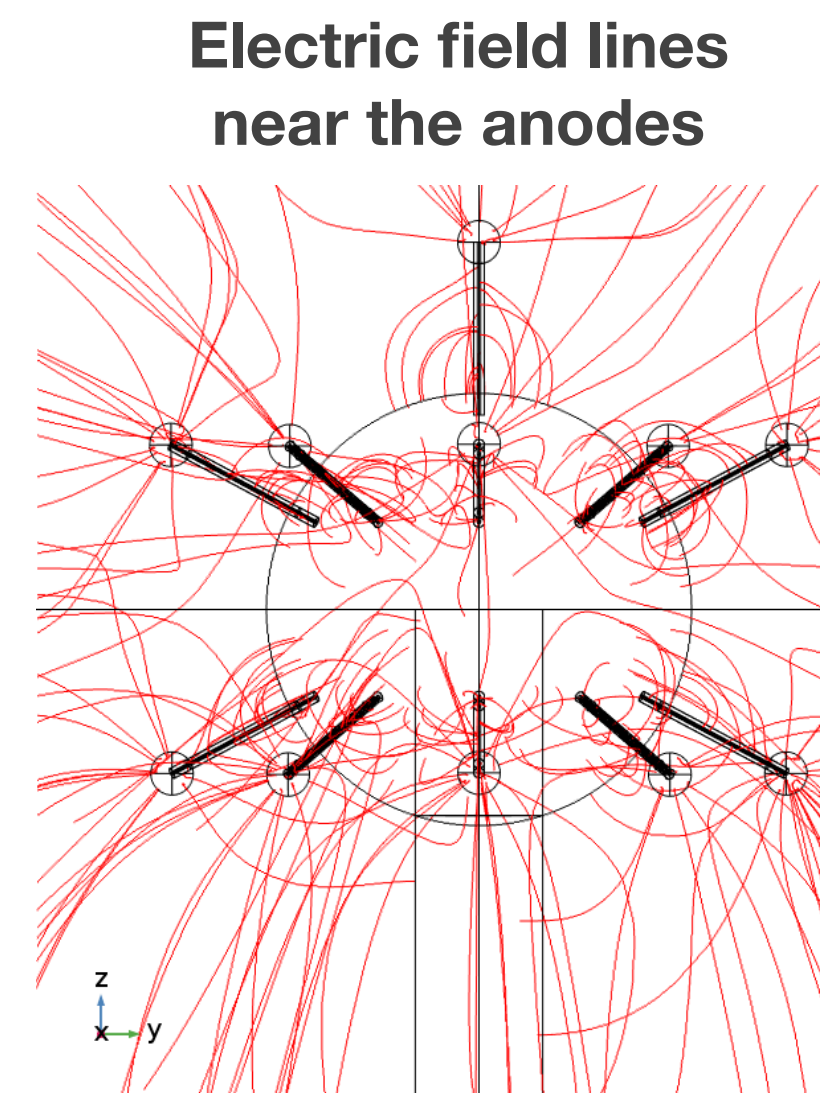
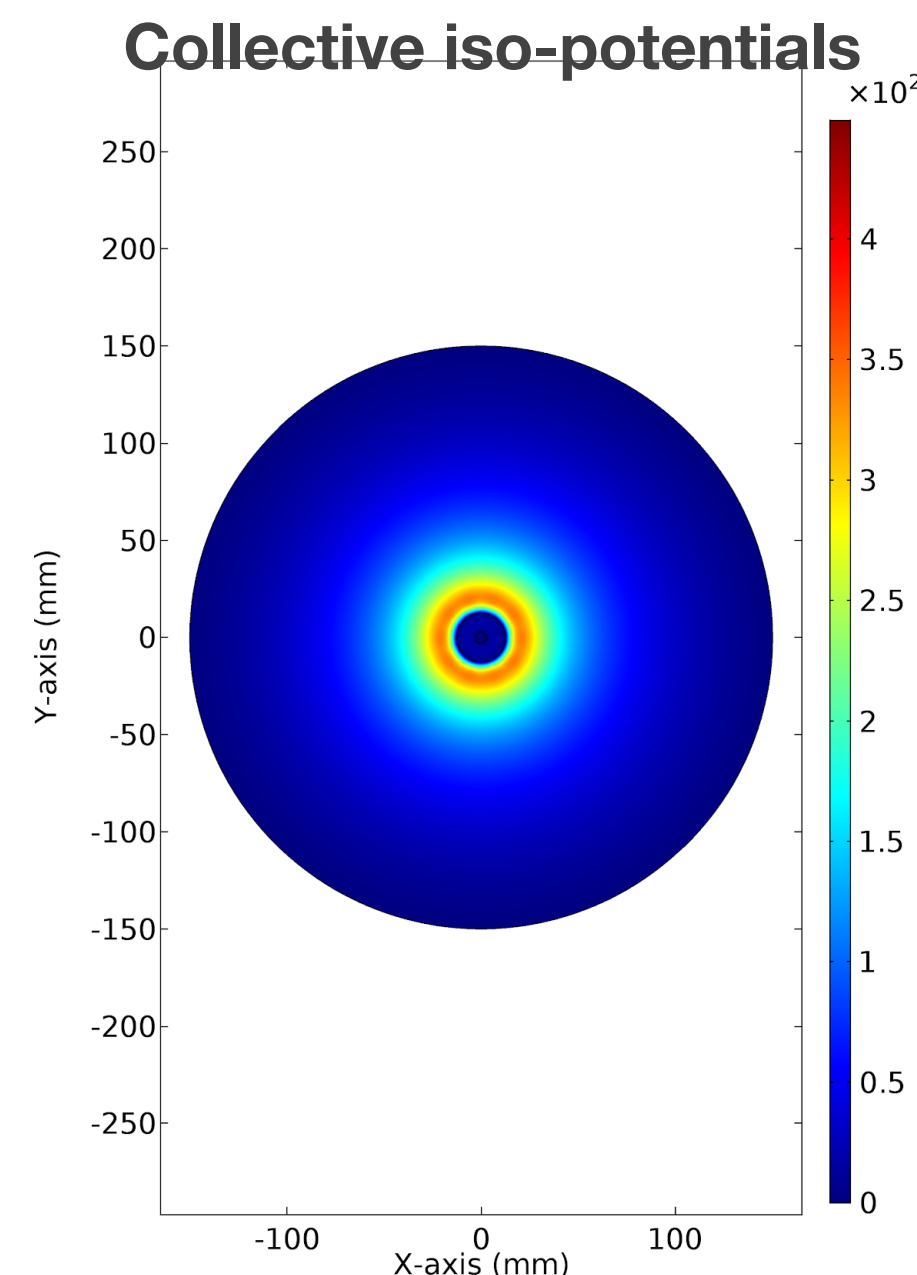


JINST 15 (2020) 11, 11



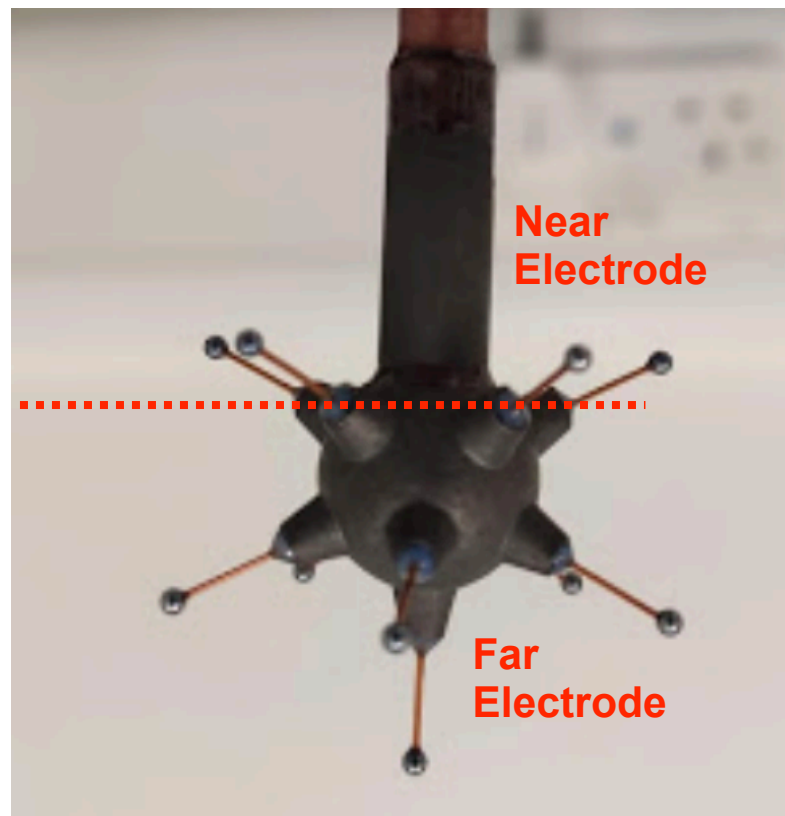
Αχιυός (greek. sea urchin)

- **ACHINOS: Multi-anode sensor**
 - Multiple anodes placed at equal radii
 - Decoupling drift and amplification fields
 - Opportunity: individual anode read-out

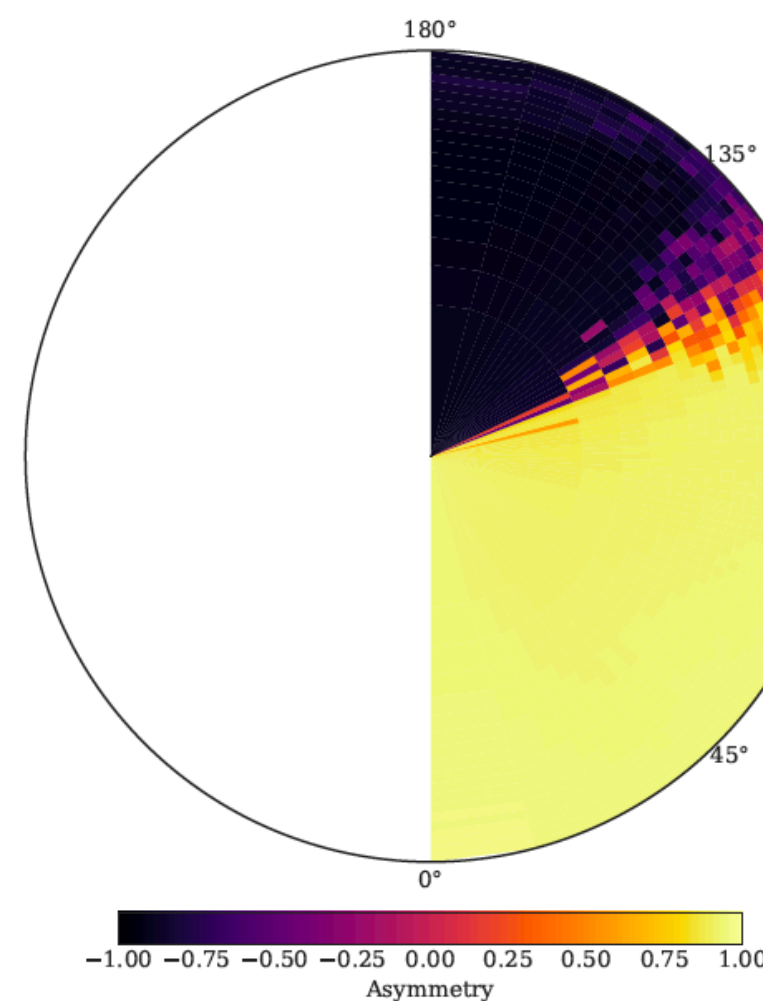


Fiducialisation and event reconstruction

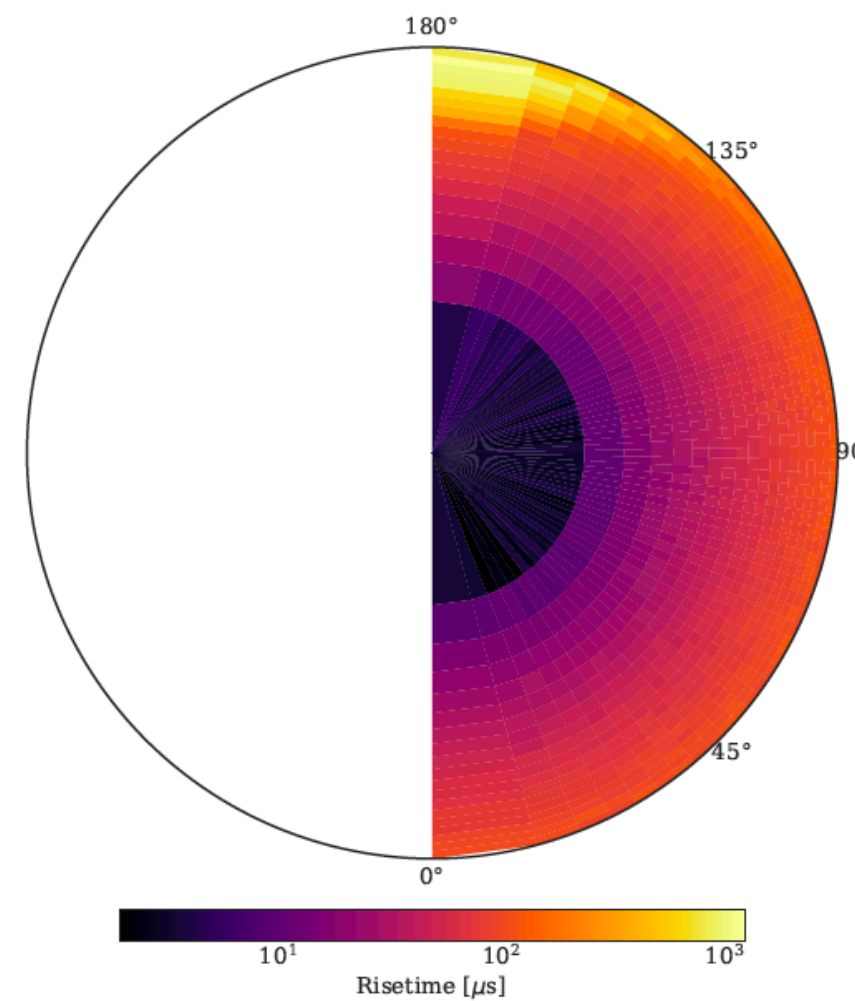
Studies with the Birmingham simulation framework



Signal Asymmetry

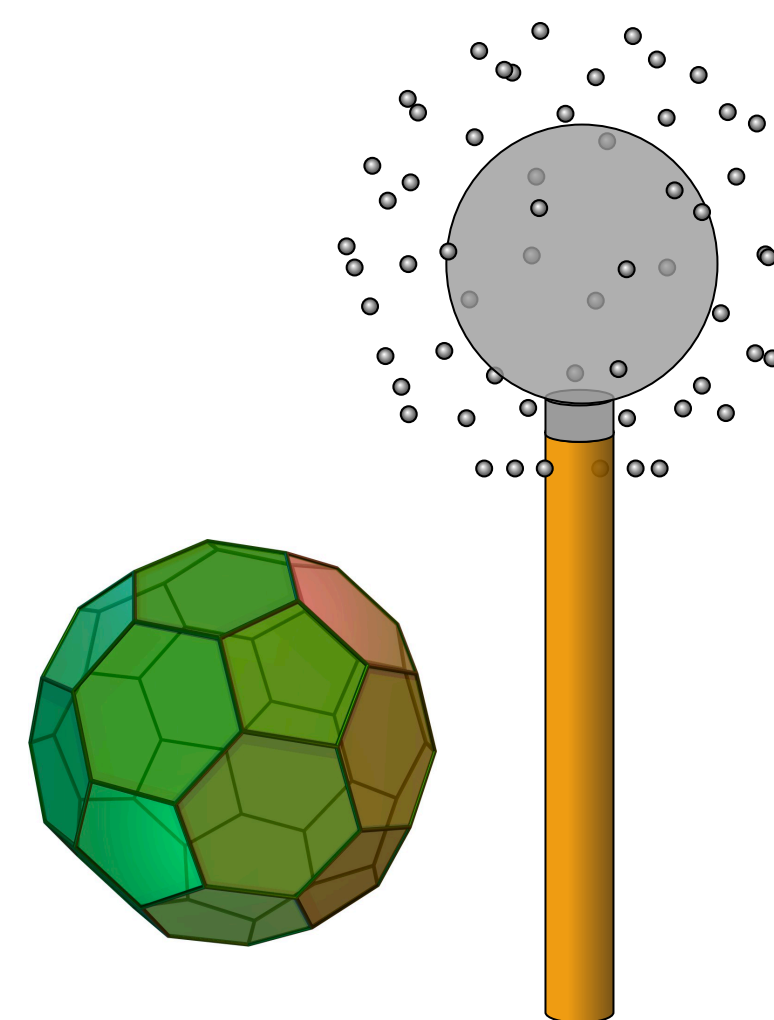


Signal Rise time

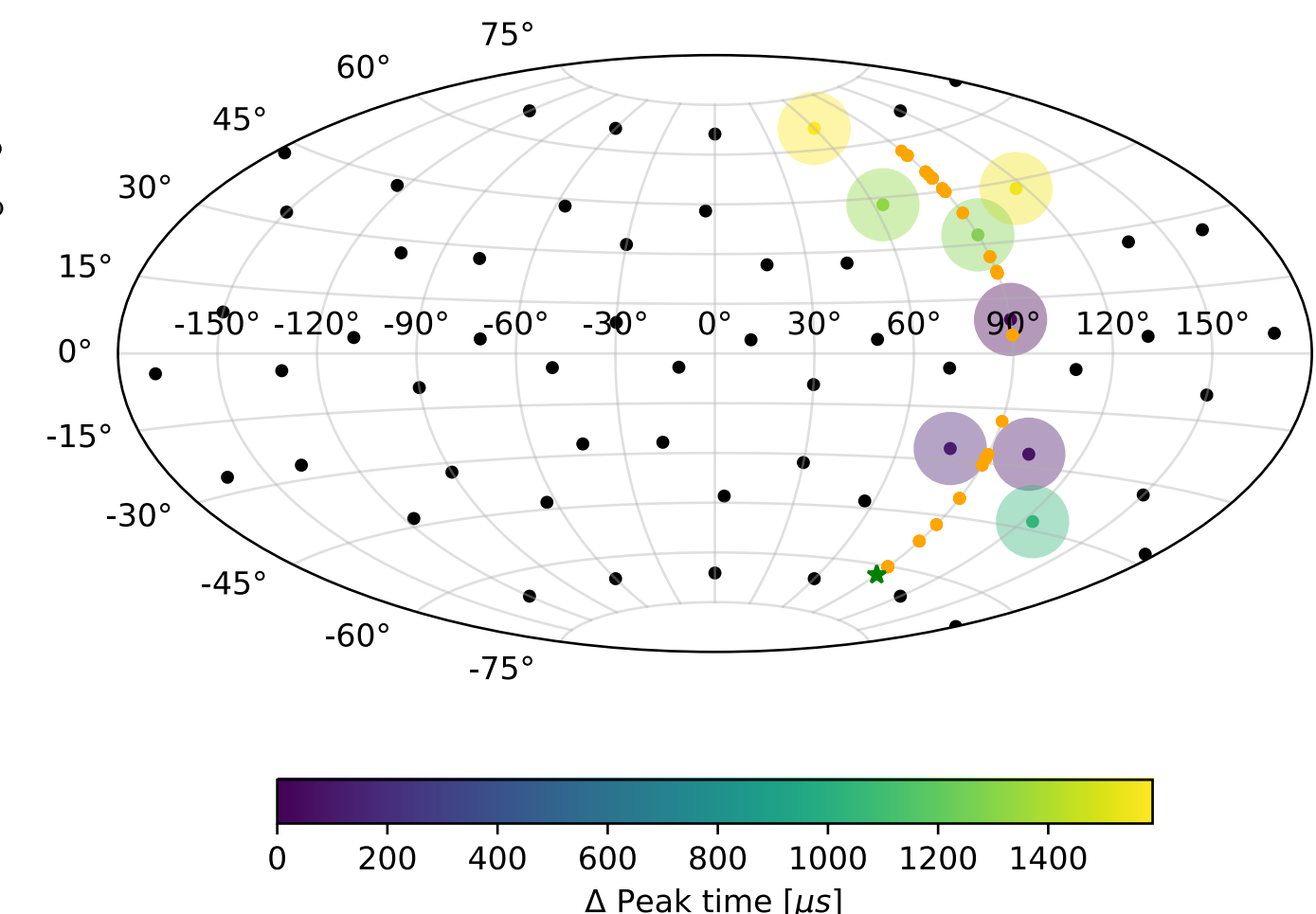


In the future

Individual anode read-out → track reconstruction



60-anodes (truncated icosahedron)



- Reading out individual ACHINOS anodes: position of interaction can be reconstructed
- First tests: Separate the anodes in two electrodes “Near” and “Far” (from the rod)
 - Asymmetry of pulse amplitudes: zenith angle
 - Pulse rise-time: radius

Summary

NEWS-G has a rich R&D programme towards exploring new DM territory with Spherical Proportional Counters

- Significant instrumentation advances
 - Electroformation, ACHINOS, ...
- Several detectors scheduled/planned for the coming years
- Sensitivity down to the neutrino floor

Many physics opportunities: DM Nuclear (spin dependent and independent) and electron recoils, $0\nu\beta\beta$, ...

