# DarkSPHERE: Search for Light Dark Matter with a Spherical Proportional Counter

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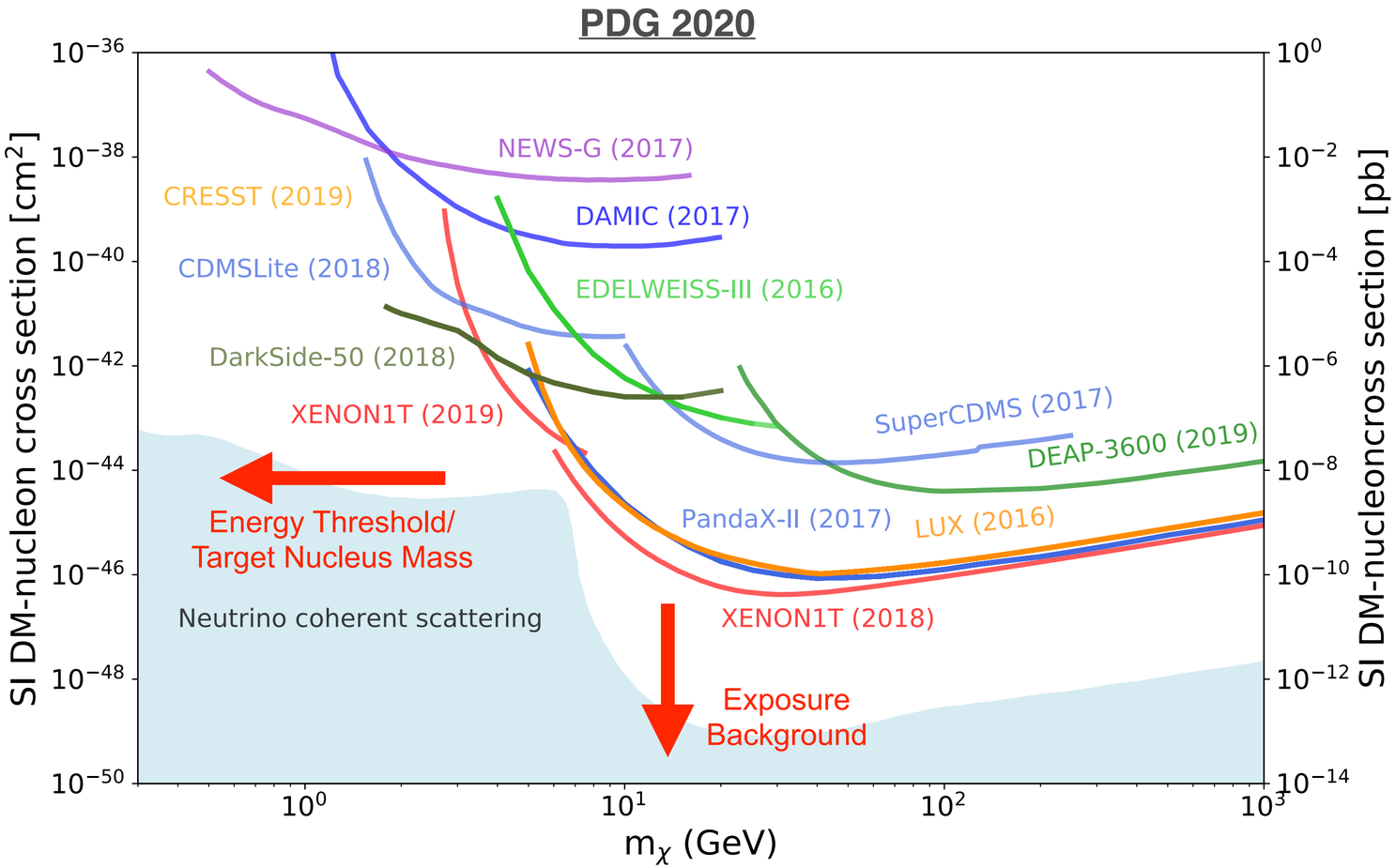
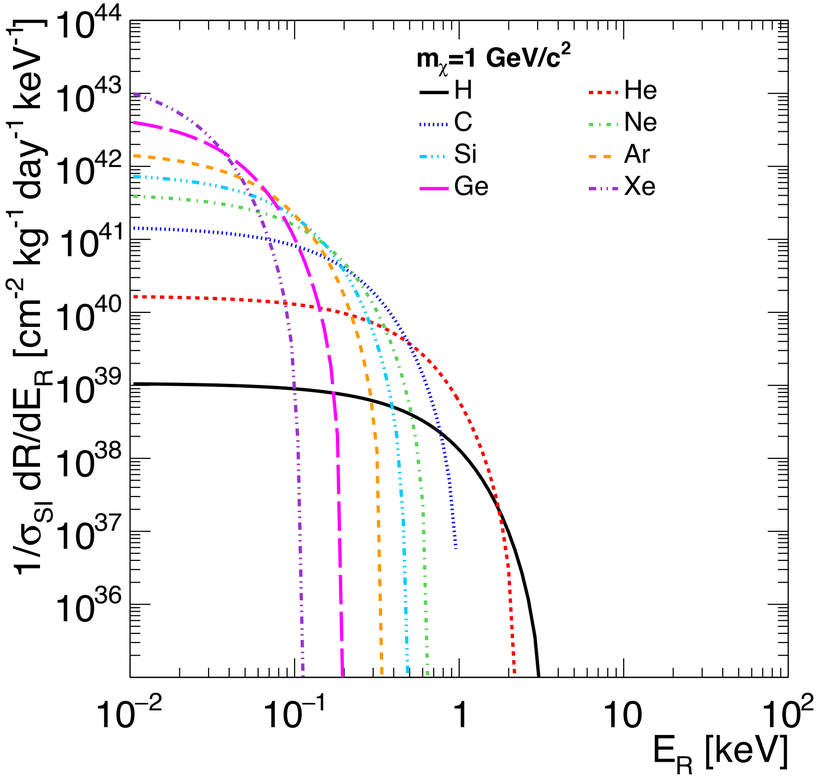
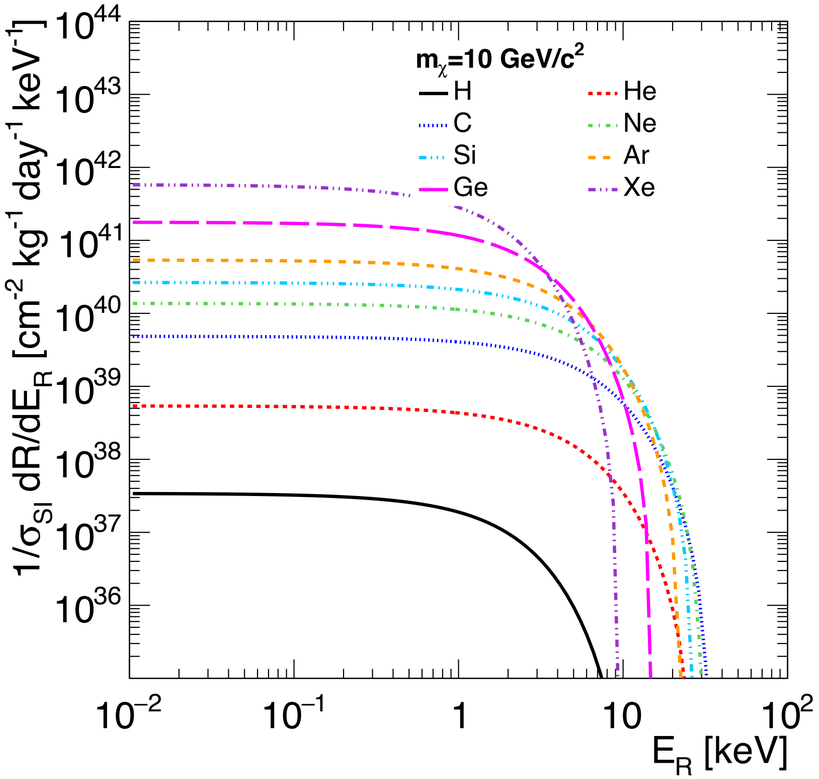
# Direct Search for DM

- Plethora of evidence for Dark Matter
- Absence of conclusive evidence in WIMP-preferred region
  - Lee-Weinberg Limit, ~2 GeV to ~1 TeV
- Much weaker constraints 0.1-10 GeV mass range
  - Region has attracted theoretical interest



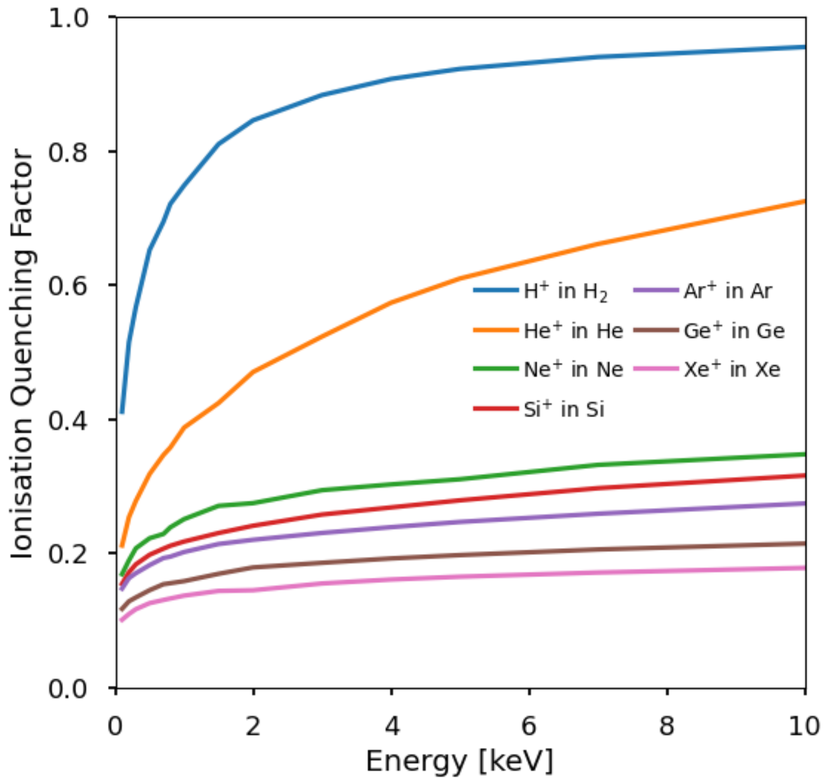
# Light DM Detection: Kinematics




- **Kinematic matching** means **low-mass targets** are favourable for light-DM detection by nuclear recoils

# Light DM Detection: Ionisation Quenching




- Favourable ionisation quenching factor
  - ➡ Direct detection using light target gases (H, He, Ne)

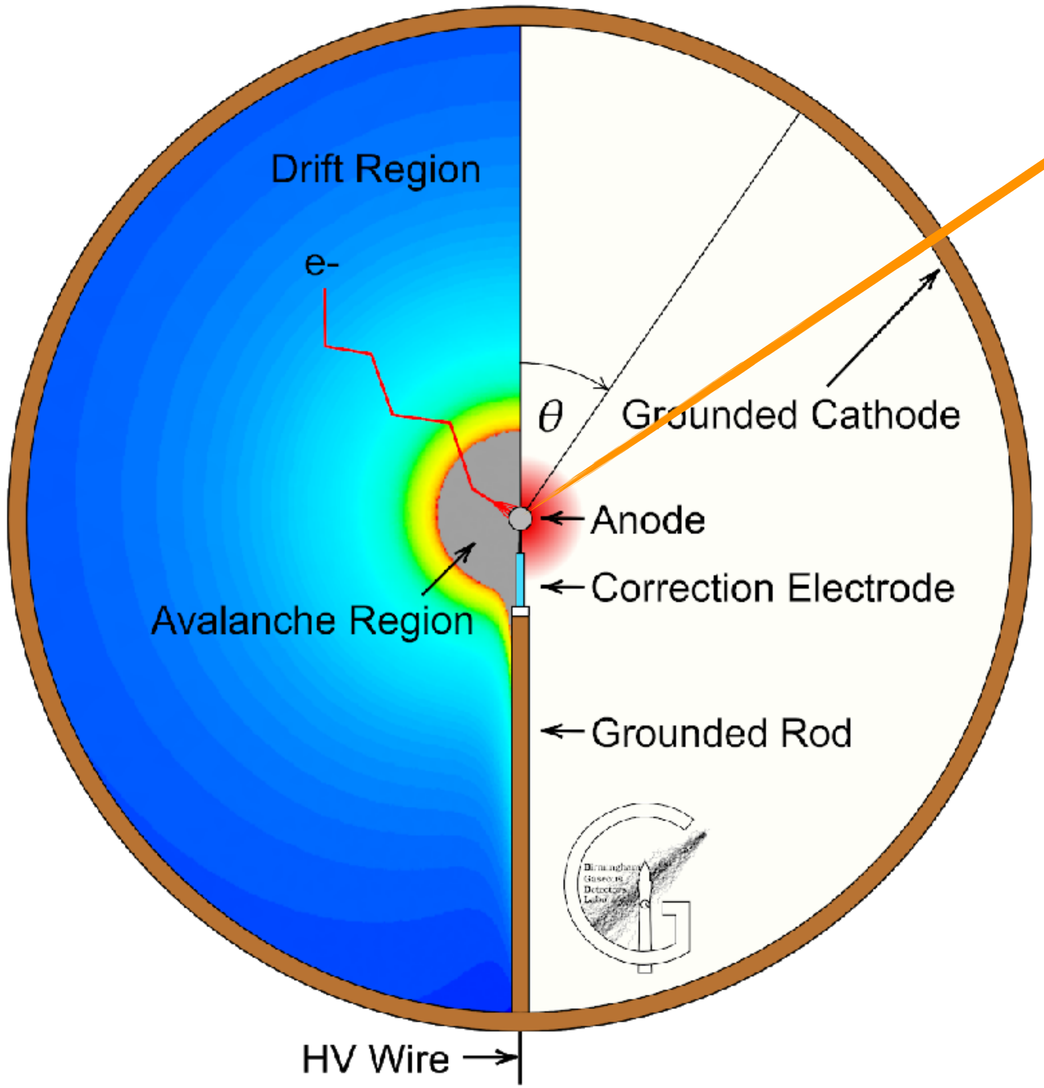
# NEWS-G Collaboration

**N**ew **E**xperiments **W**ith **S**pheres - **G**as

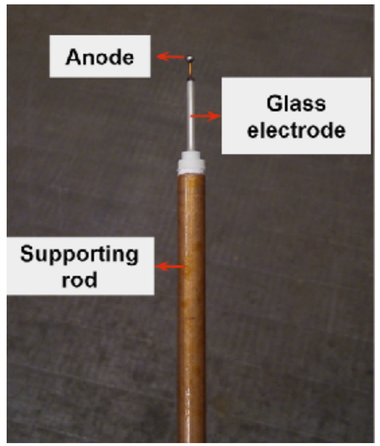
Light DM searches with a novel gaseous detector, the spherical proportional counter

# Spherical Proportional Counter

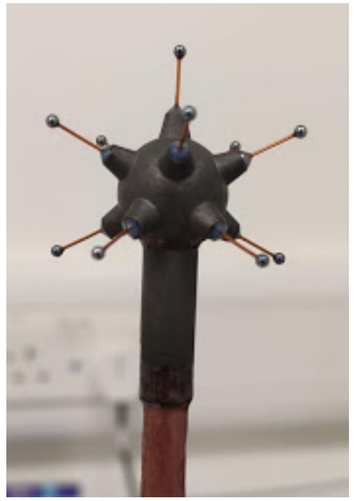
JINST, 2008, P09007




Single-anode readout or Multi-anode Readout



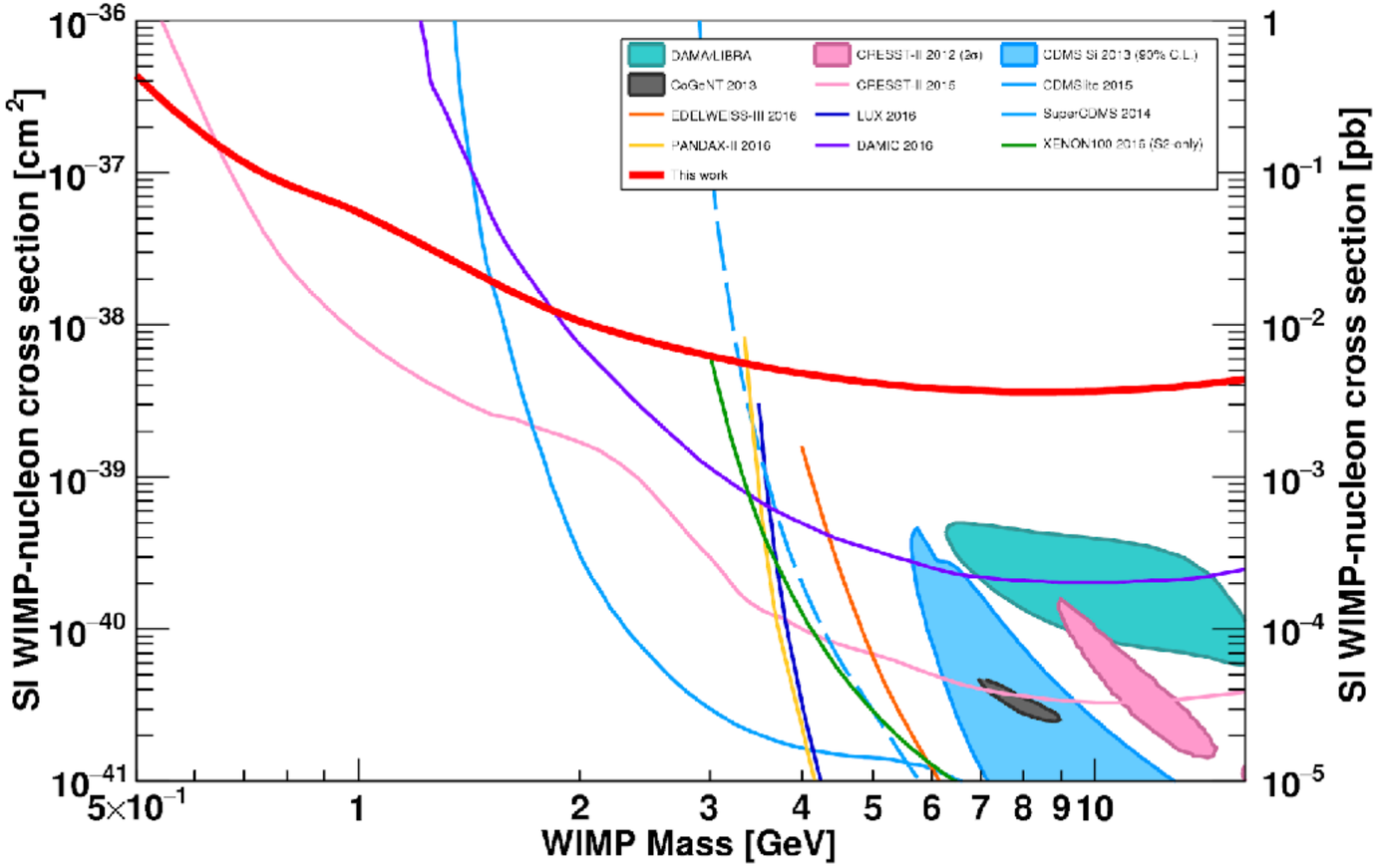

JINST, 13, 2018, no.11, P11006



JINST 15 (2020) 11, 11

I. Giomataris and G. Charpak in CEA Saclay (sphere was previously a LEP RF cavity)

# NEWS-G@LSM First Results




- ⌀60 cm detector, SEDINE, with NOSV copper
- Ne:$CH_4$ (99.3%:0.7%) at 3.1 bar (280 g)
- 9.6 kg day exposure (34.1 days total)

Astropart.Phys. 97 (2018) 54-62

Contents lists available at ScienceDirect
Astroparticle Physics
journal homepage: www.elsevier.com/locate/astropartphys

First results from the NEWS-G direct dark matter search experiment at the LSM

Q. Arnaud[a,*], D. Asner[b], J.-P. Bard[c], A. Brossard[a,c], B. Cai[a], M. Chapellier[a], M. Clark[a], E.C. Corcoran[c], T. Dandl[e], A. Dastgheibi-Fard[f], K. Dering[a], P. Di Stefano[a], D. Durnford[a], G. Gerbier[a], I. Giomataris[c], P. Gorel[g], M. Gros[c], O. Guillaudin[h], E.W. Hoppe[b], A. Kamaha[a], I. Katsioulas[c], D.G. Kelly[d], R.D. Martin[a], J. McDonald[a], J.-F. Muraz[h], J.-P. Mols[c], X.-F. Navick[c], T. Papaevangelou[c], F. Piquemal[f], S. Roth[a,1], D. Santos[h], I. Savvidis[i], A. Ulrich[e], F. Vazquez de Sola Fernandez[a], M. Zampaolo[f]

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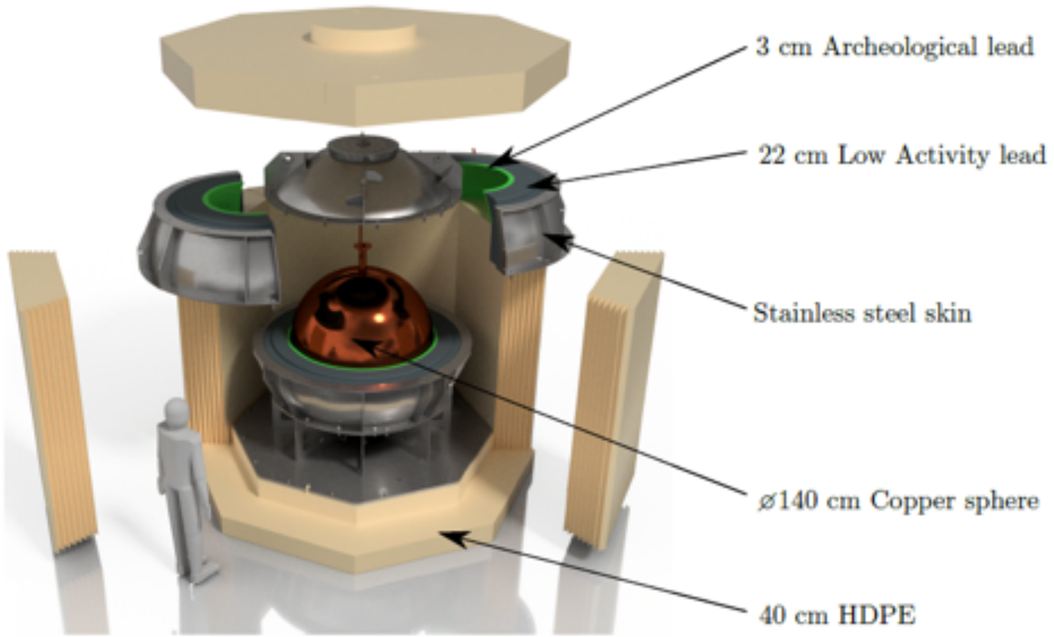
Exclusion at 90% confidence level (C.L.) of cross-sections above **$4.4\times10^{-37}$ cm$^2$** for a **0.5 GeV/c$^2$** DM particle


*Limit set on spin independent DM coupling with standard assumptions on DM velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM*

# SNOGLOBE

- New ⌀130 cm detector
- 4N (99.99% pure) Aurubis copper
- Now being commissioned in SNOLAB



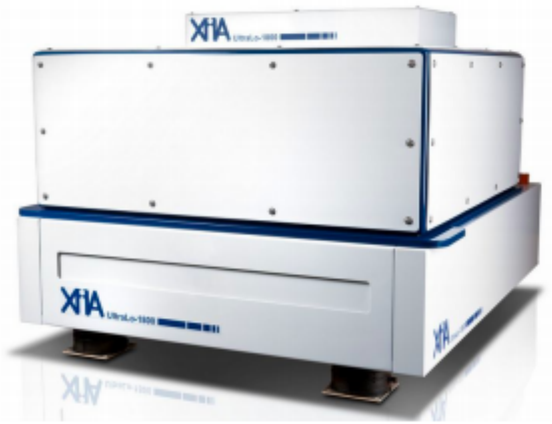

In LSM

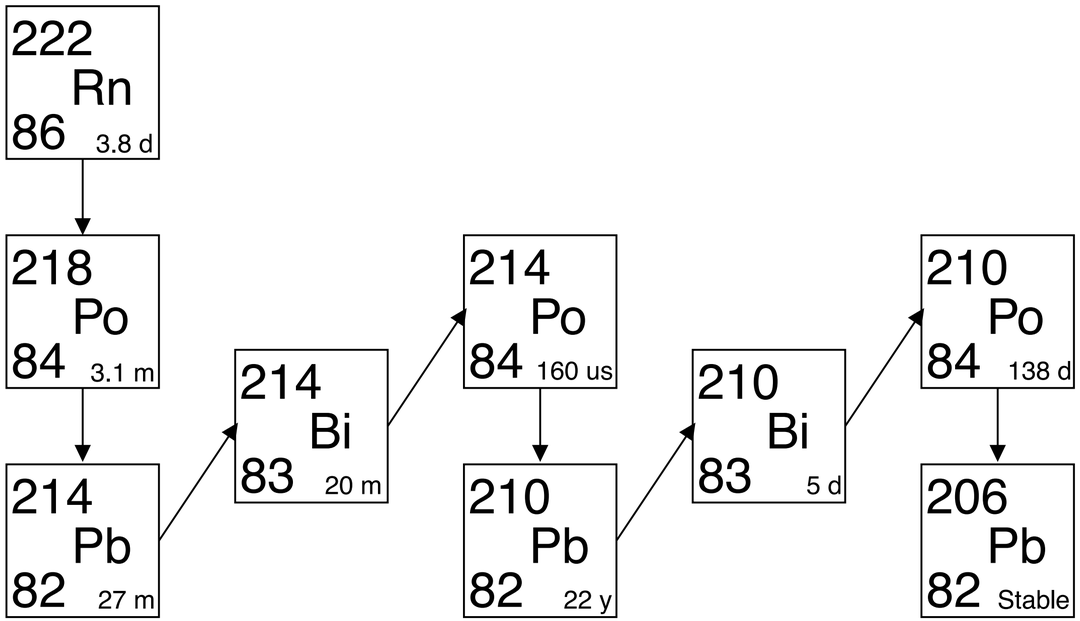
Location in SNOLAB

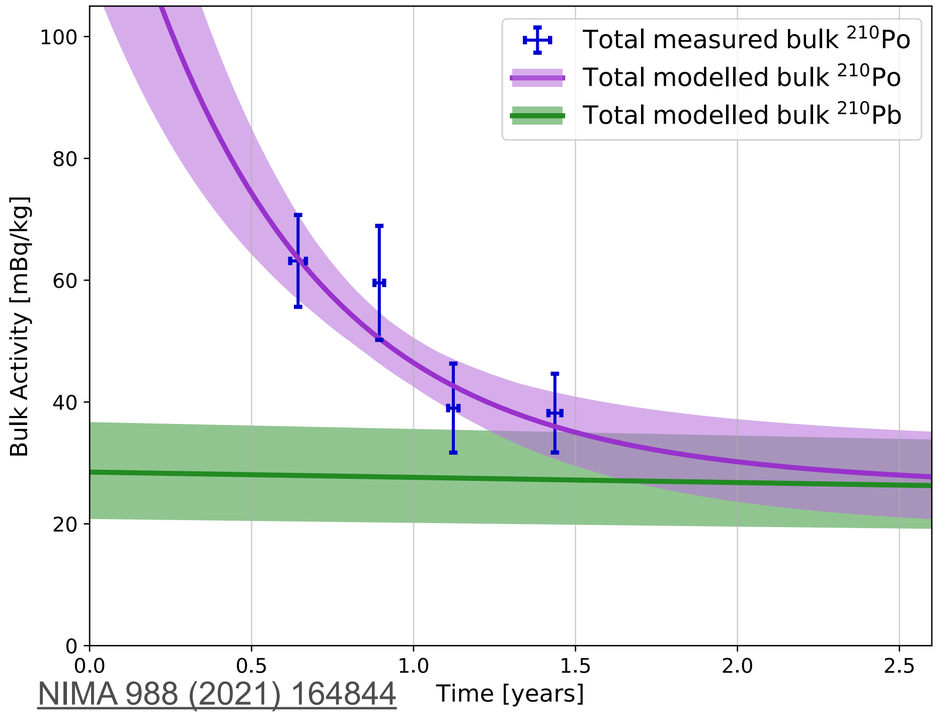
# Radioactivity of Copper

- U/Th content assessment with ICP-MS: very optimistic
  - Secular equilibrium broken by $^{222}$Rn contamination
- Recently, measure $^{210}$Po alpha and infer $^{210}$Pb activity with XIA UltraLo-1800 NIM A 828 (2016) 22–36
  - 29±10 mBq/kg $^{210}$Pb in NEWS-G copper
    - Becomes main background

XIA UltraLo-1800
https://www.xia.com/ultralo-theory.html



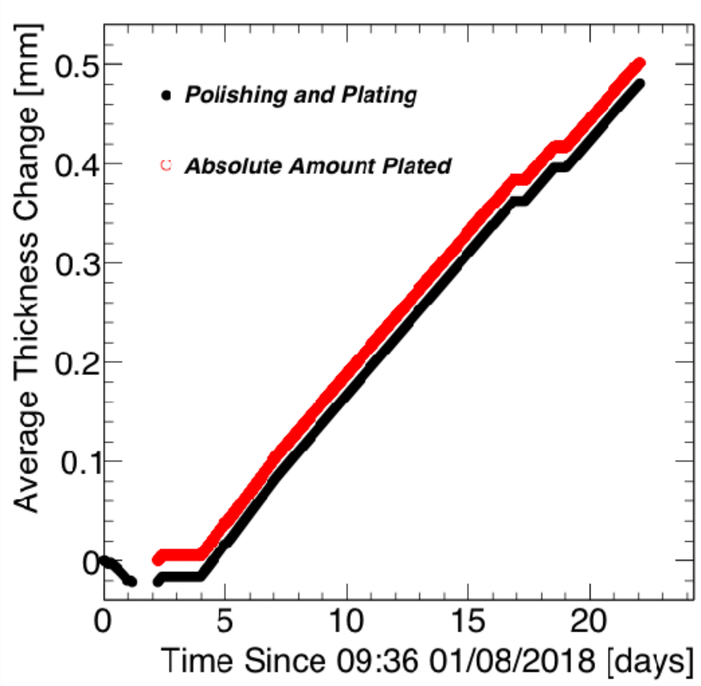


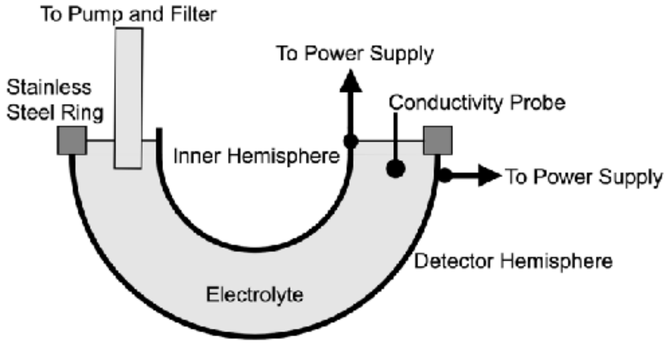



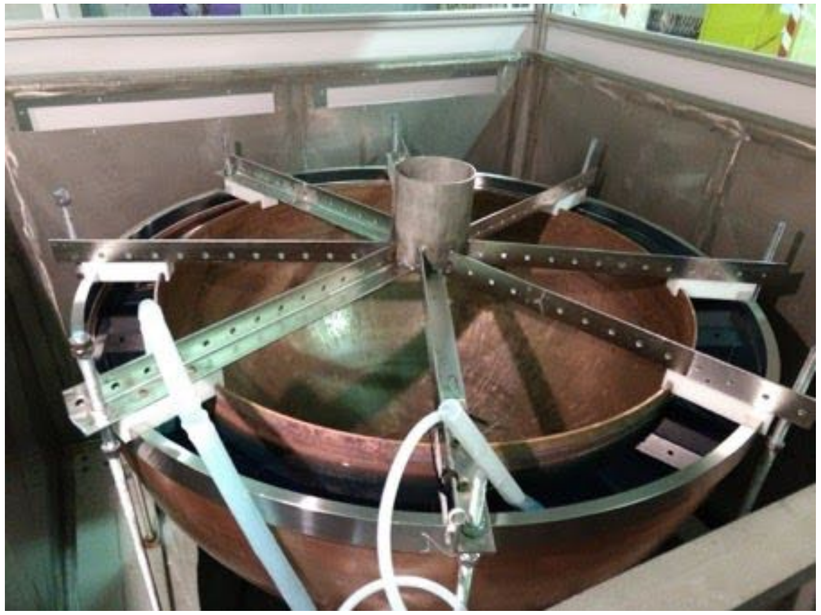

NIMA 988 (2021) 164844

# Copper Electroplating

- Copper electroplating
  - Preferentially deposits copper: purification
- 500 µm electroplated layer to detector inner surface
- Background reduction by factor 2.3 <1 keV (Geant4)



- Electroplated in LSM
- Expertise from PNNL with strong Birmingham involvement

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# Copper Electroplating

- Copper deposition rate achieved ~36 µm/day
  - Potential to electroform full detector on feasible time scale
  - ICP-MS assay of sample comparable to other EF copper
- EF copper below sensitivity of XIA UltraLo-1800 <3 mBq/kg

ICP-MS Assay

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

Nuclear Inst. and Methods in Physics Research, A 988 (2021) 164844

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

(NEWS-G Collaboration)

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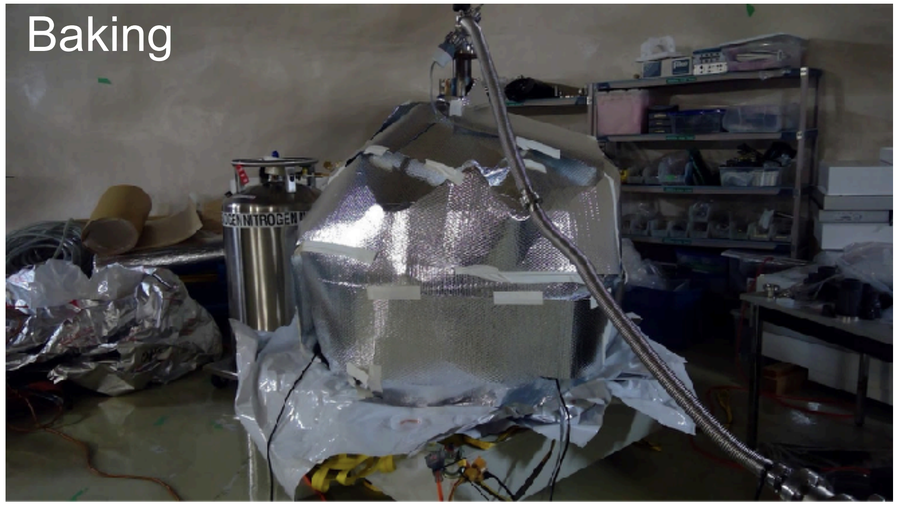
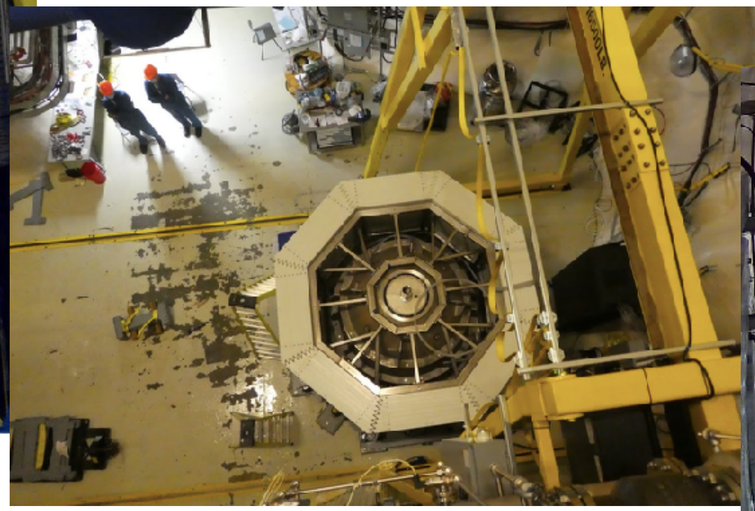
# Current Status





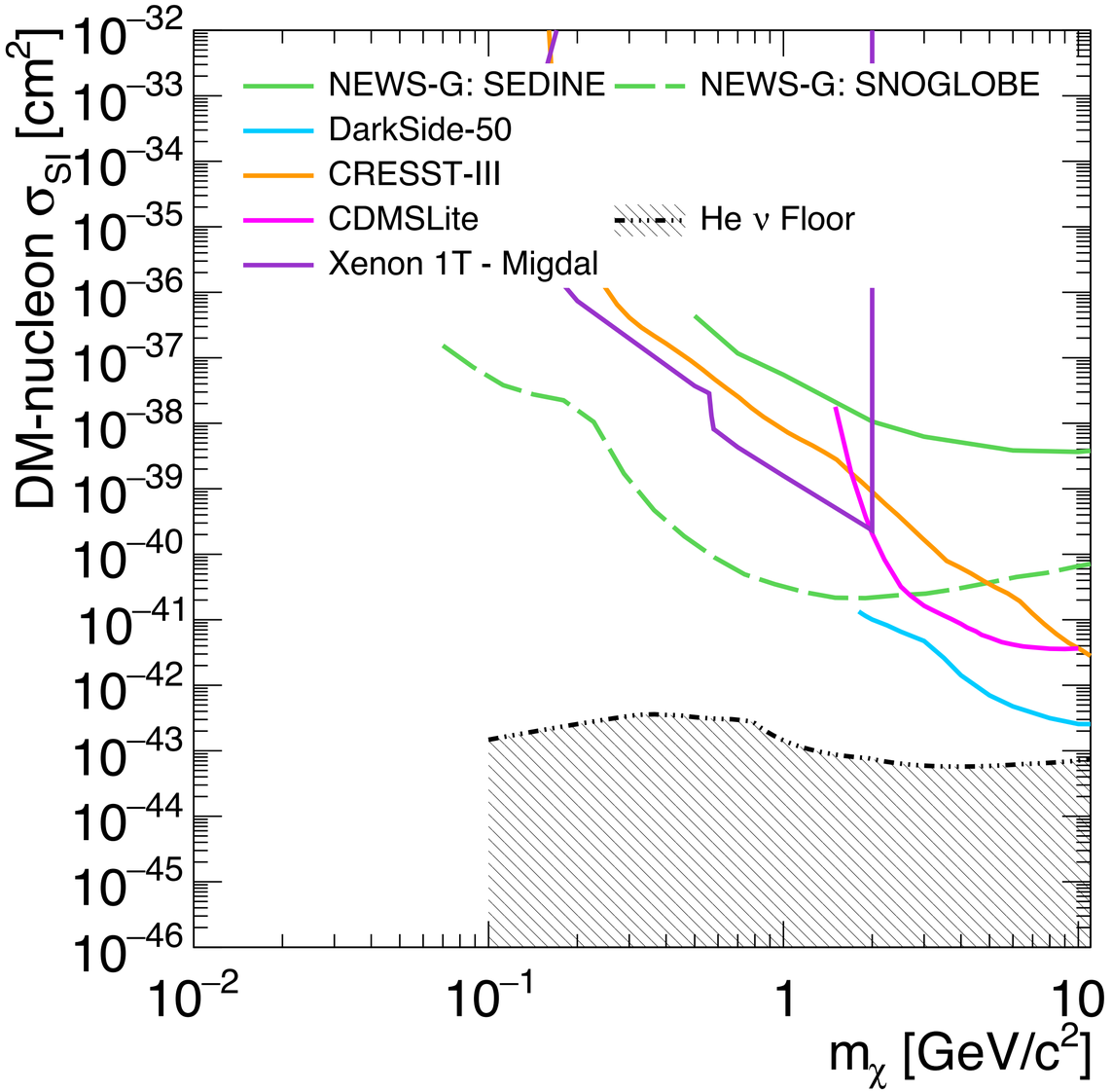

Installation in shield

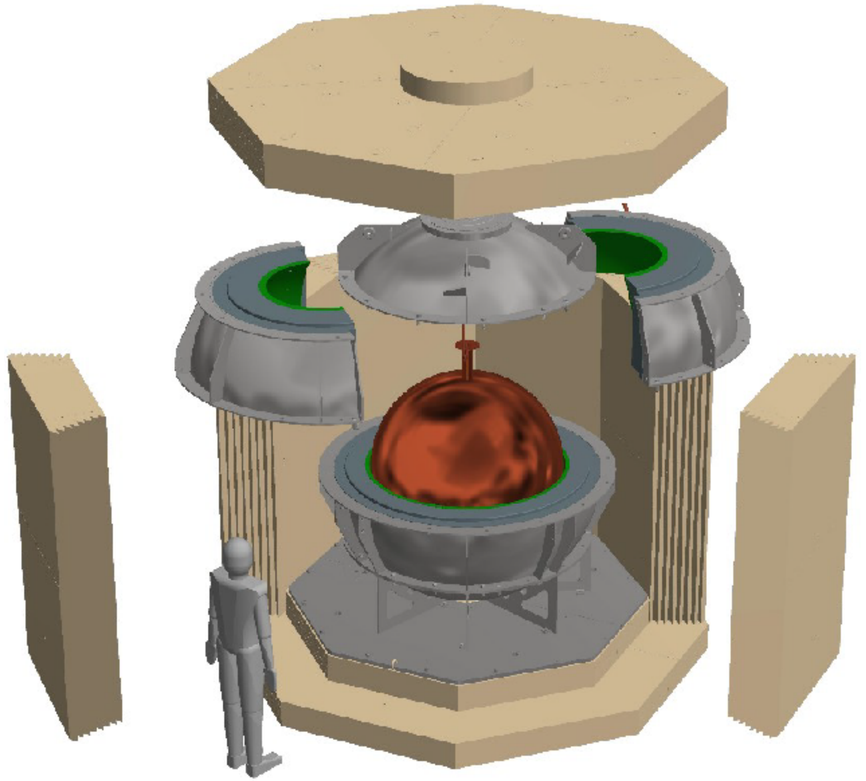


Installing PE shield

Complete assembly

# NEWS-G@SNOLAB: Physics Potential



**Assumptions**

Flat background (1.78 dru)

Ne:$CH_4$ (90%:10%)

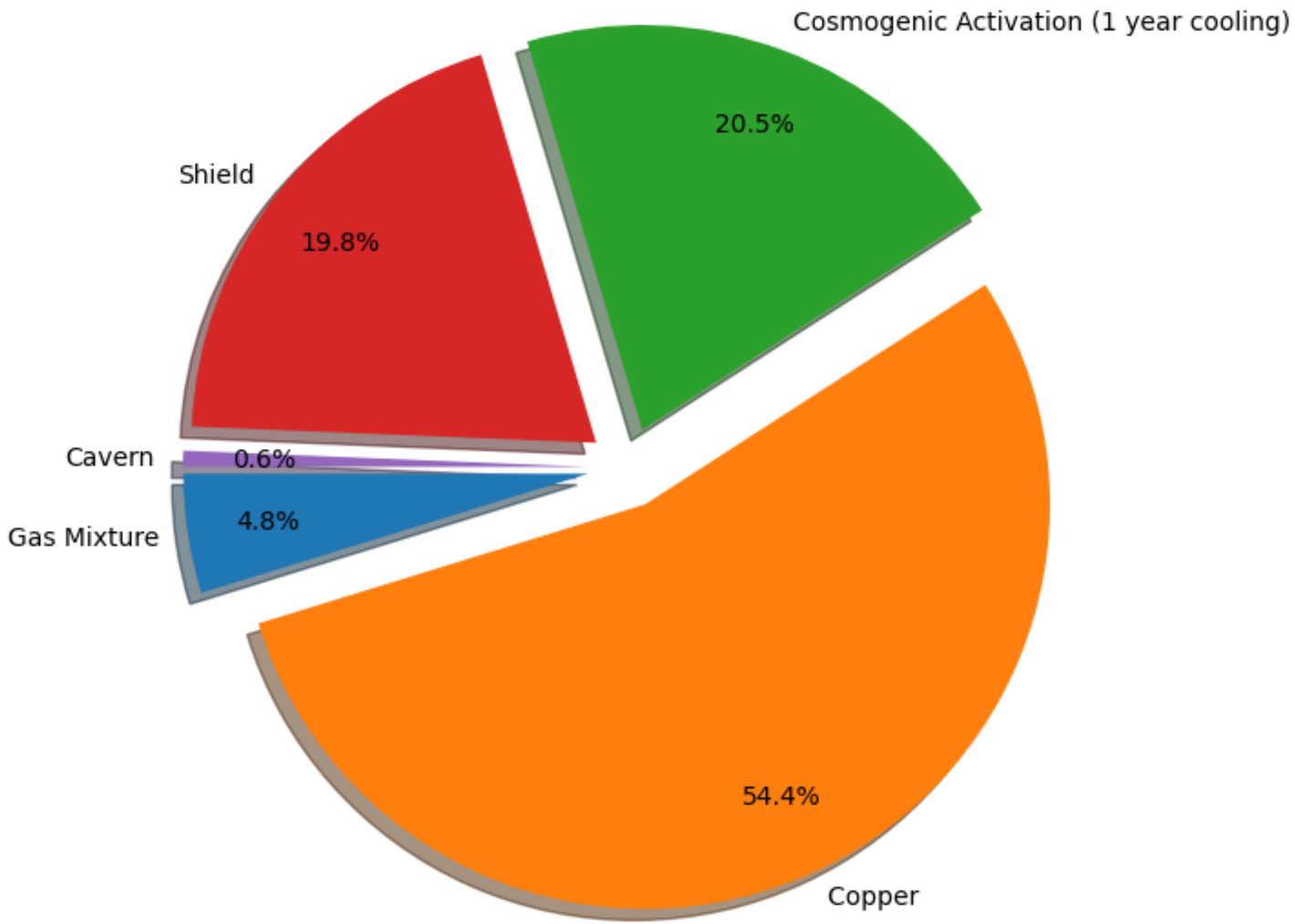
Exposure 20 kg*days

Energy window [14 $eV_{ee}$, 1 $keV_{ee}$]

F=0.2, θ=0.12

SRIM quenching factor

# Backgrounds in NEWS-G@SNOLAB



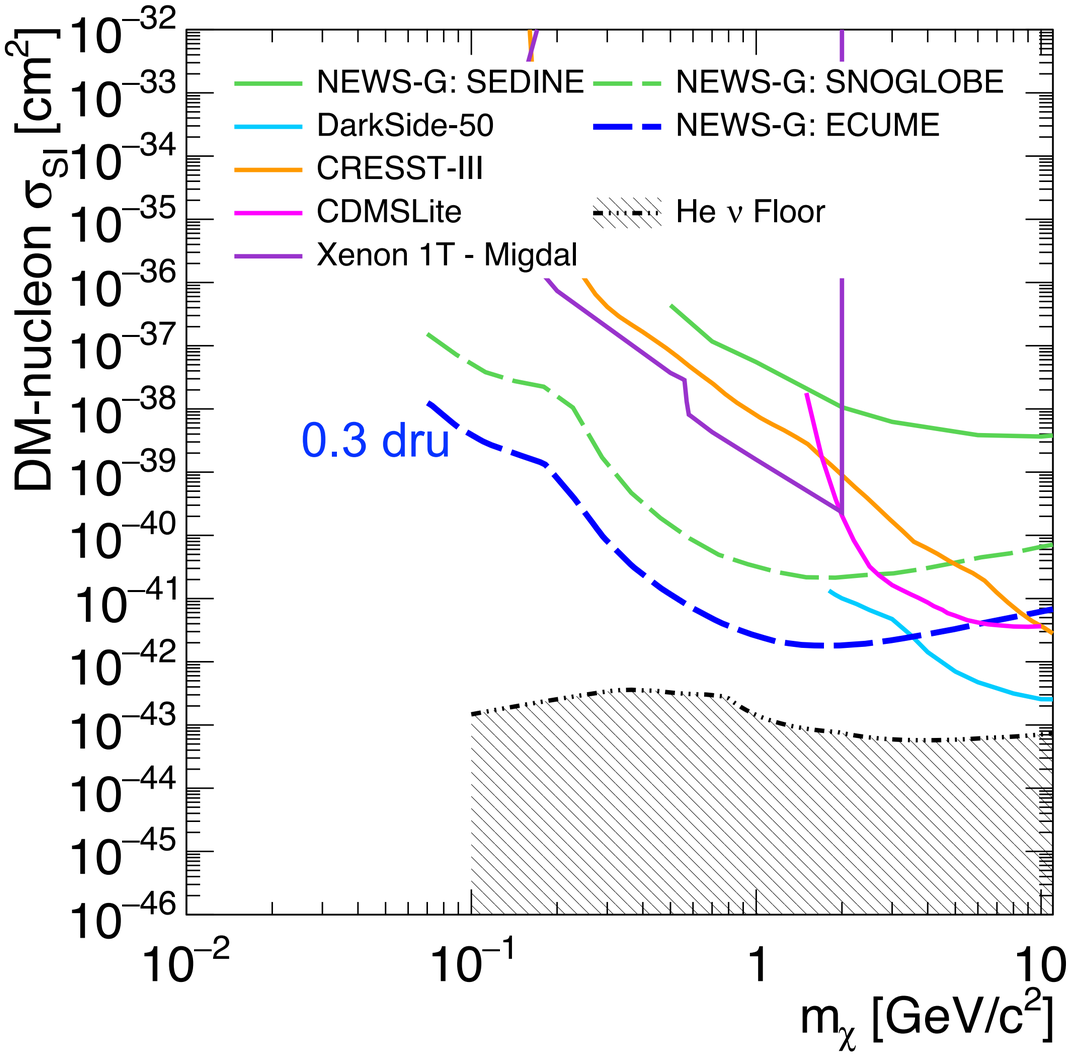

Numbers from A. Brossard, PhD Thesis, 2020

# Next Stage

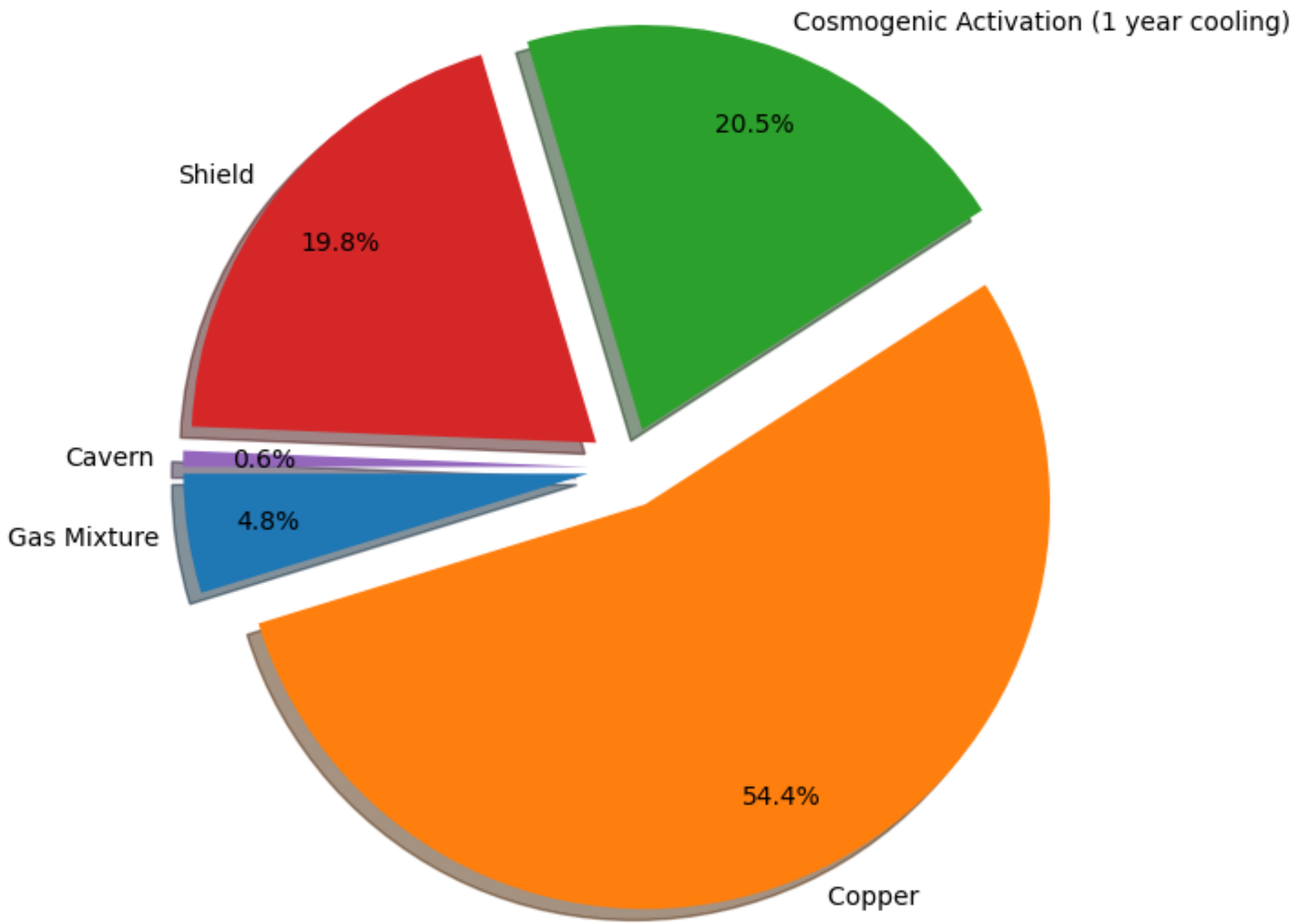
- **ECUME** - an underground-electroformed 140 cm sphere
  - Electroformed in SNOLAB
  - No machining or welding - grow sphere directly
- Builds on achievements of NEWS-G electroplating
  - 36 µm/day → ~1 mm/month

**Status:**

- R&D for 30 cm prototype bath at PNNL
  - Procurement of parts underway
- Full-scale planned to be underway by Autumn 2021
- ECUME is initially dedicated to NEWS-G, but after it will be an **electroplating facility** available in SNOLAB



# Backgrounds in NEWS-G@SNOLAB




Numbers from A. Brossard, PhD Thesis, 2020

# DarkSPHERE

⌀3 m fully underground-electroformed detector

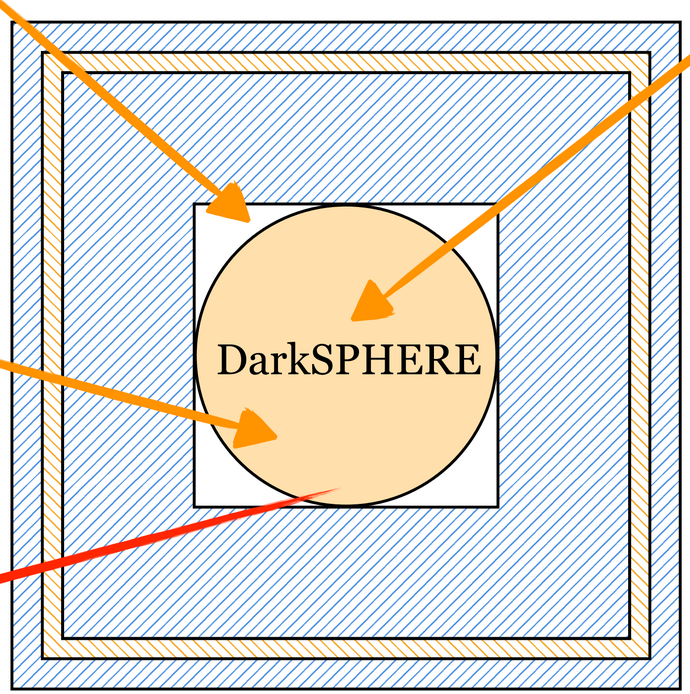
Operation with 5 bar $He:C_4H_{10}$ (90%:10%)

(27 kg)

➡Large mass of light targets

Multi-physics potential

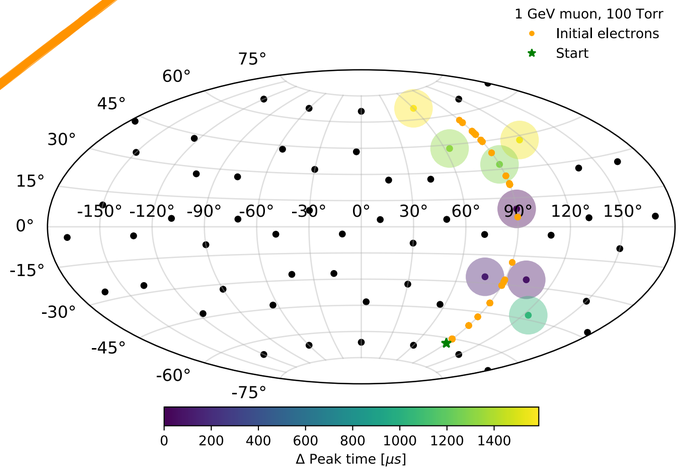
- Dark Matter search
- 0ν2β decay search
- CEvNs physics

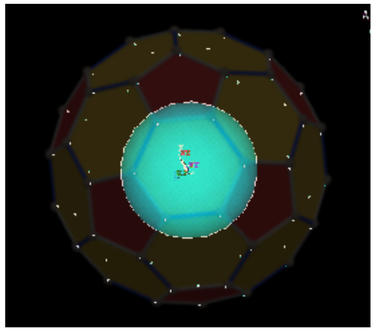


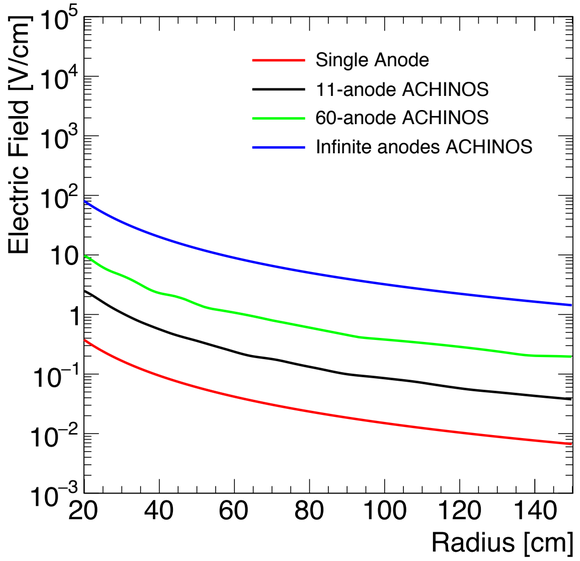

Multi-anode readout with potential for individual anode read-out (TPC-like mode)

➡Studying in simulation

JINST 15 (2020) 06, C06013

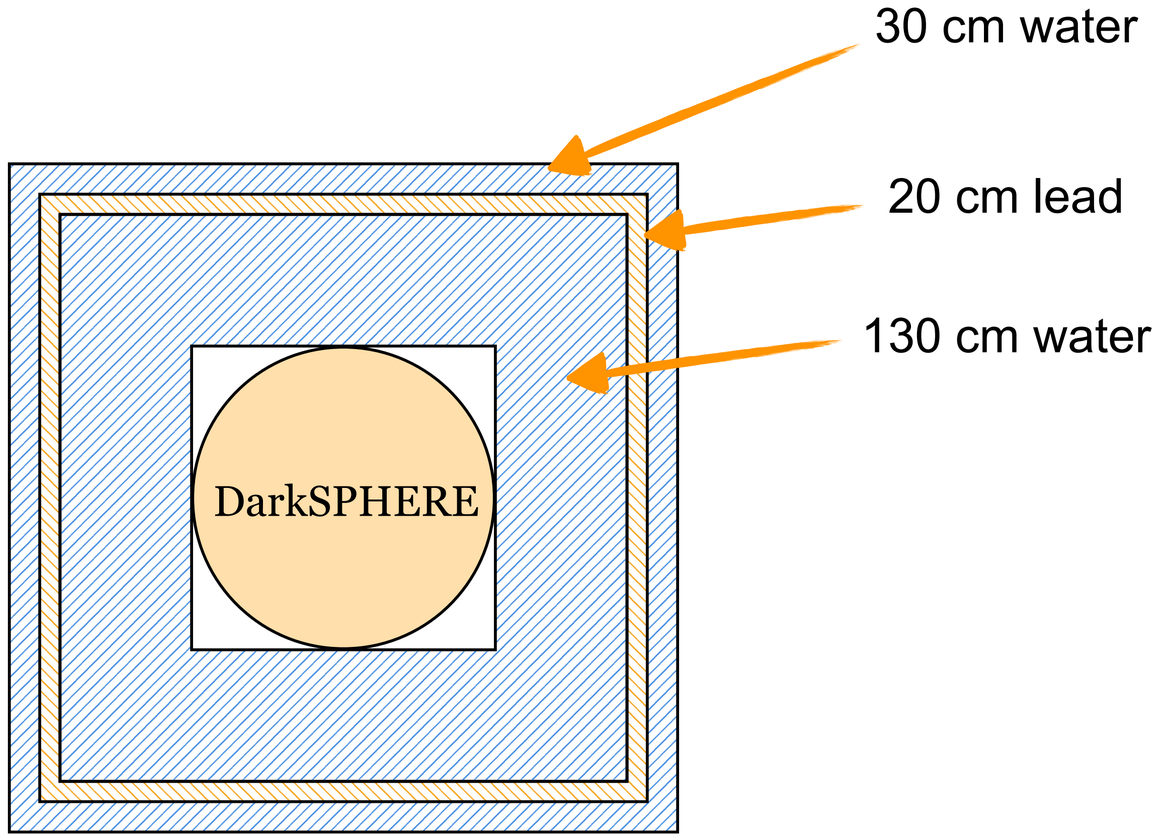




# DarkSPHERE Shielding

- **Goal**: background from shield and environment to be same order as that from EF copper (0.002 dru <1 keV)
- Working to constraints of Boulby's Large Experimental Cavern (7x7x7 $m^3$)
- 2 options considered:
  - Only water
  - Water-lead-water
- Only water needs 3.5 m to achieve goal
  - Wouldn't fit in currently available space
- Water-lead-water is viable option
- Also investigating active component (i.e. liquid scintillator)

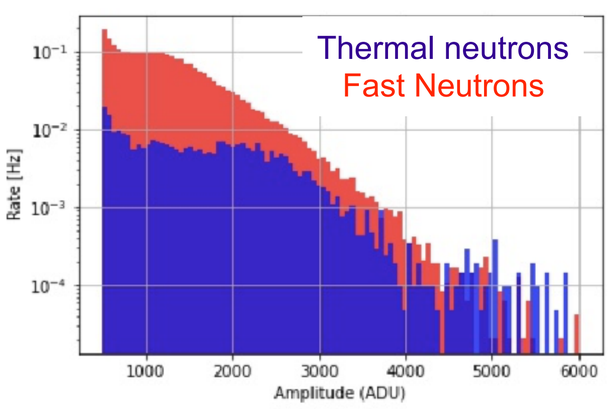


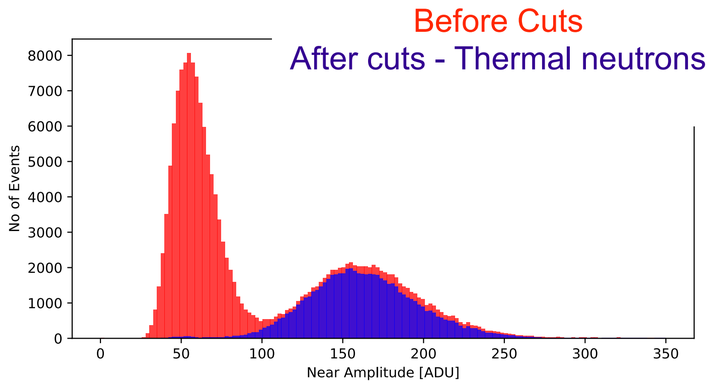

| Configuration | Environmental Photons [dru] | Environmental Neutrons [dru] |
|---|---|---|
| Water (2 m) | 8 | 0.002 |
| Water (3.5 m) | 0.002 | <0.002 |
| Water-lead | 0.005 | 0.002 |


J.Radioanal.Nucl.Chem. 298 (2013) 3, 1483-1489
NIMA 505 (2003) 688-698
Astropart.Phys. 22 (2005) 409-420

# Spherical Proportional Counters in Boulby

- ⌀30 cm detector arrived in Boulby Dec. 2019
- Aim to study:
  - Instrumentation R&D in controlled environment
    - e.g. space charge measurements
  - Neutron flux
    - thermal/fast neutrons
    - n/γ discrimination
  - Gas purification studies
    - Purpose-built $O_2/H_2O$ filter with U. of Liverpool




Neutron Measurements in Birmingham - 1 bar $N_2$

# Summary

- Fully underground-electroformed spheres will have significantly enhanced discovery potential
- ECUME is will begin construction this year
- DarkSPHERE has potential to reach neutrino floor
  - Detailed studies of read-out and shielding underway
  - Conceptual designs conducted targeting Boulby as host
- Electroformation is the way to suppress background in rare-event search experiments
- SNOLAB's ECUME will be worlds largest underground electroformation facility
- Electroformation capability in Boulby relevant for future rare-event search experiments