UNIVERSITY OF BIRMINGHAM

Light Dark Matter Searches with DarkSPHERE in Boulby

Patrick Knights

University of Birmingham, UK

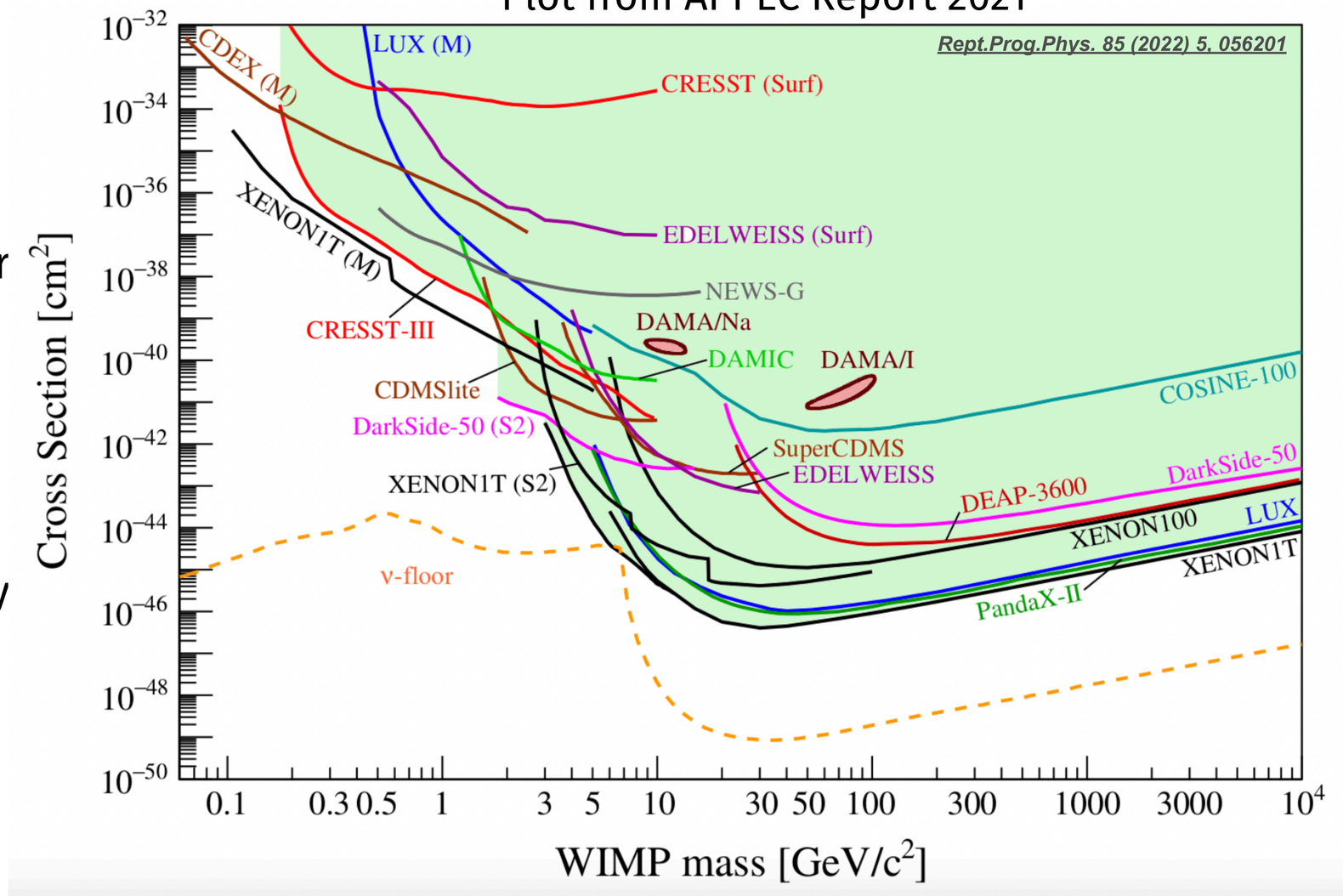
Landscape of Direct DM Searches

- Light-DM region has attracted theoretical interest

- Exploring light-DM region with nuclear recoils requires:
  - ➡Low energy threshold
  - ➡Low mass nuclei
  - ➡Novel approaches

- NEWS-G search region complementary to existing DM searches

Plot from APPEC Report 2021



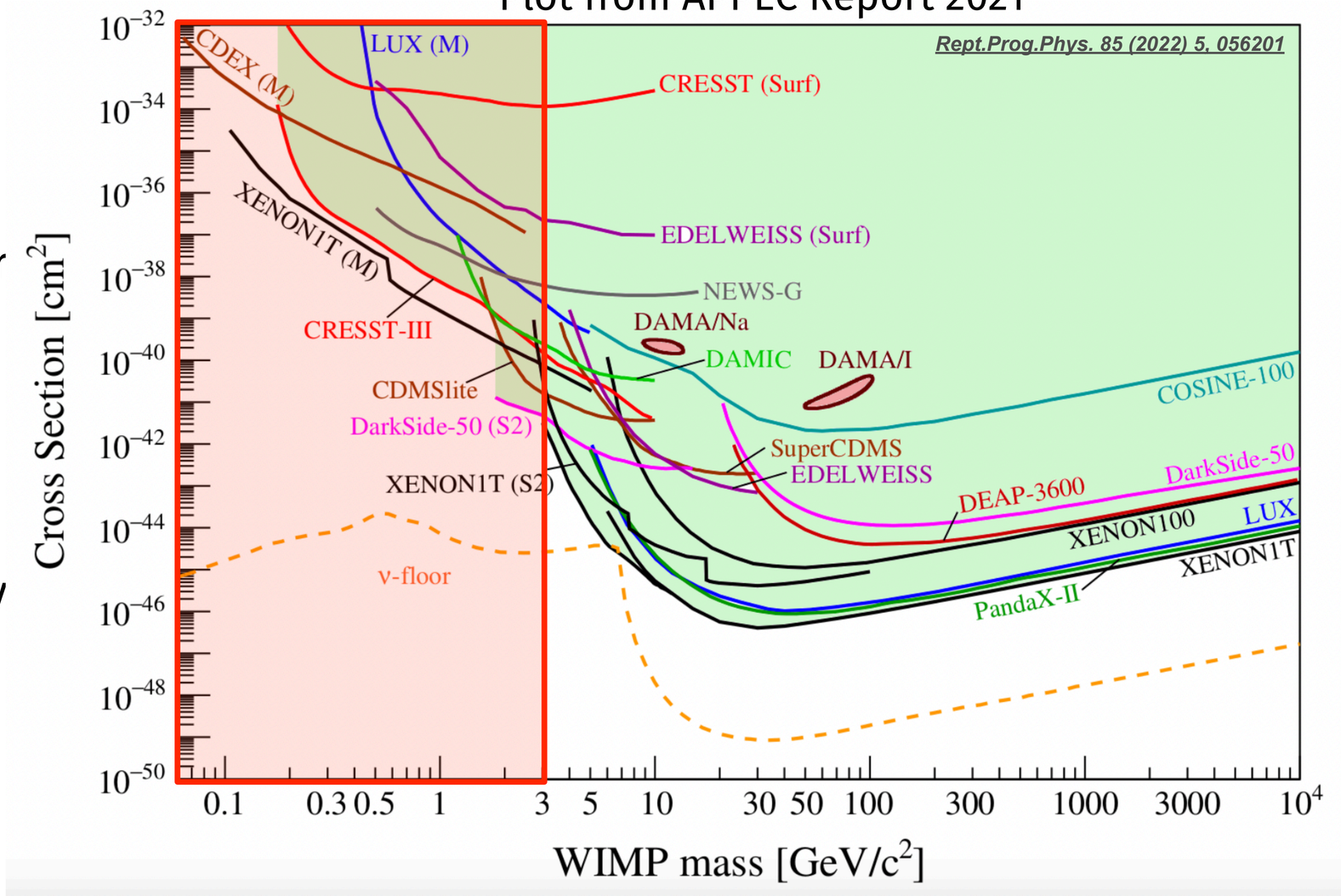
Landscape of Direct DM Searches

- Light-DM region has attracted theoretical interest

- Exploring light-DM region with nuclear recoils requires:
  - ➡Low energy threshold
  - ➡Low mass nuclei
  - ➡Novel approaches

- NEWS-G search region complementary to existing DM searches

Plot from APPEC Report 2021



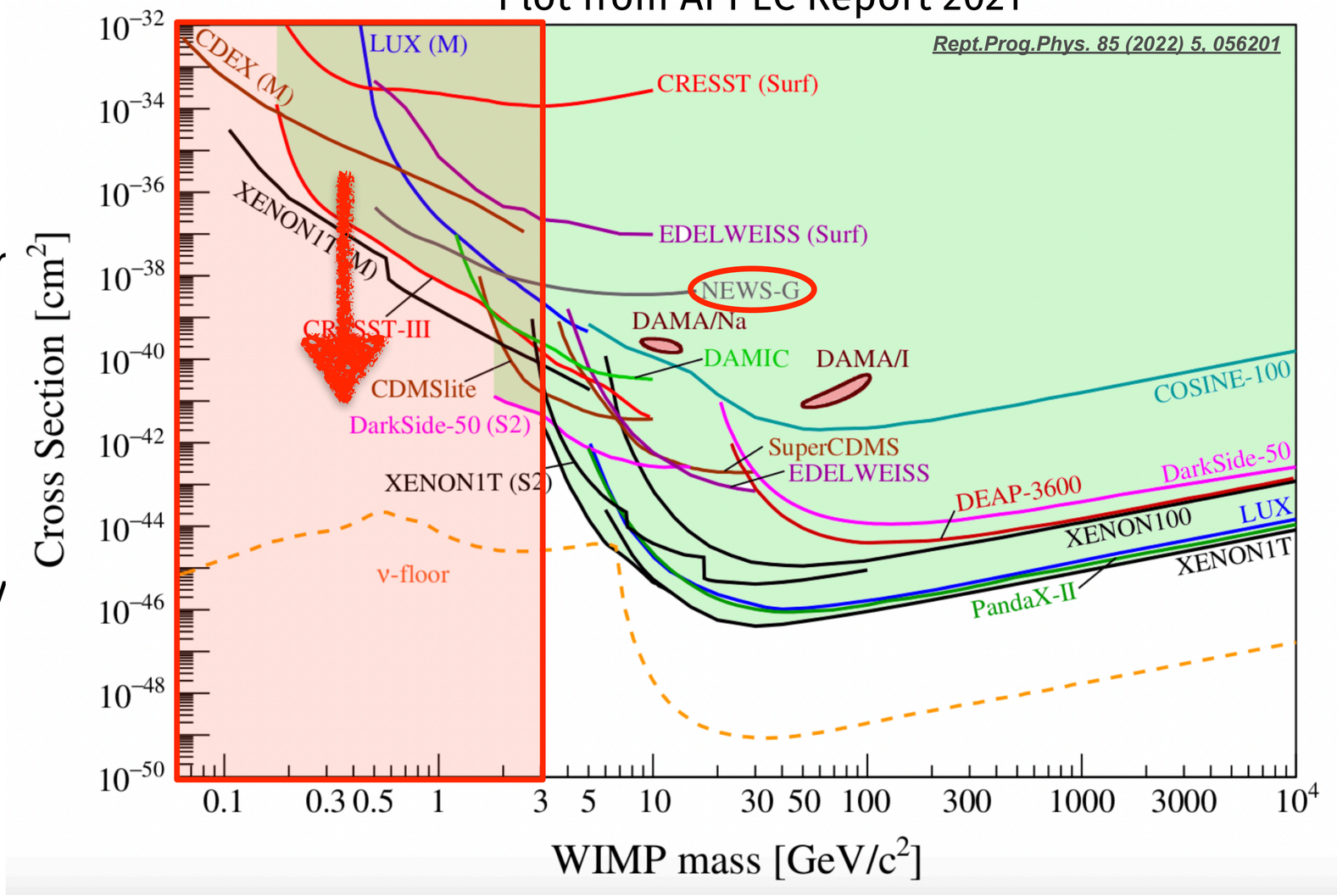
Landscape of Direct DM Searches

- Light-DM region has attracted theoretical interest

- Exploring light-DM region with nuclear recoils requires:
  - ➡Low energy threshold
  - ➡Low mass nuclei
  - ➡Novel approaches

- NEWS-G search region complementary to existing DM searches

Plot from APPEC Report 2021



NEWS-G

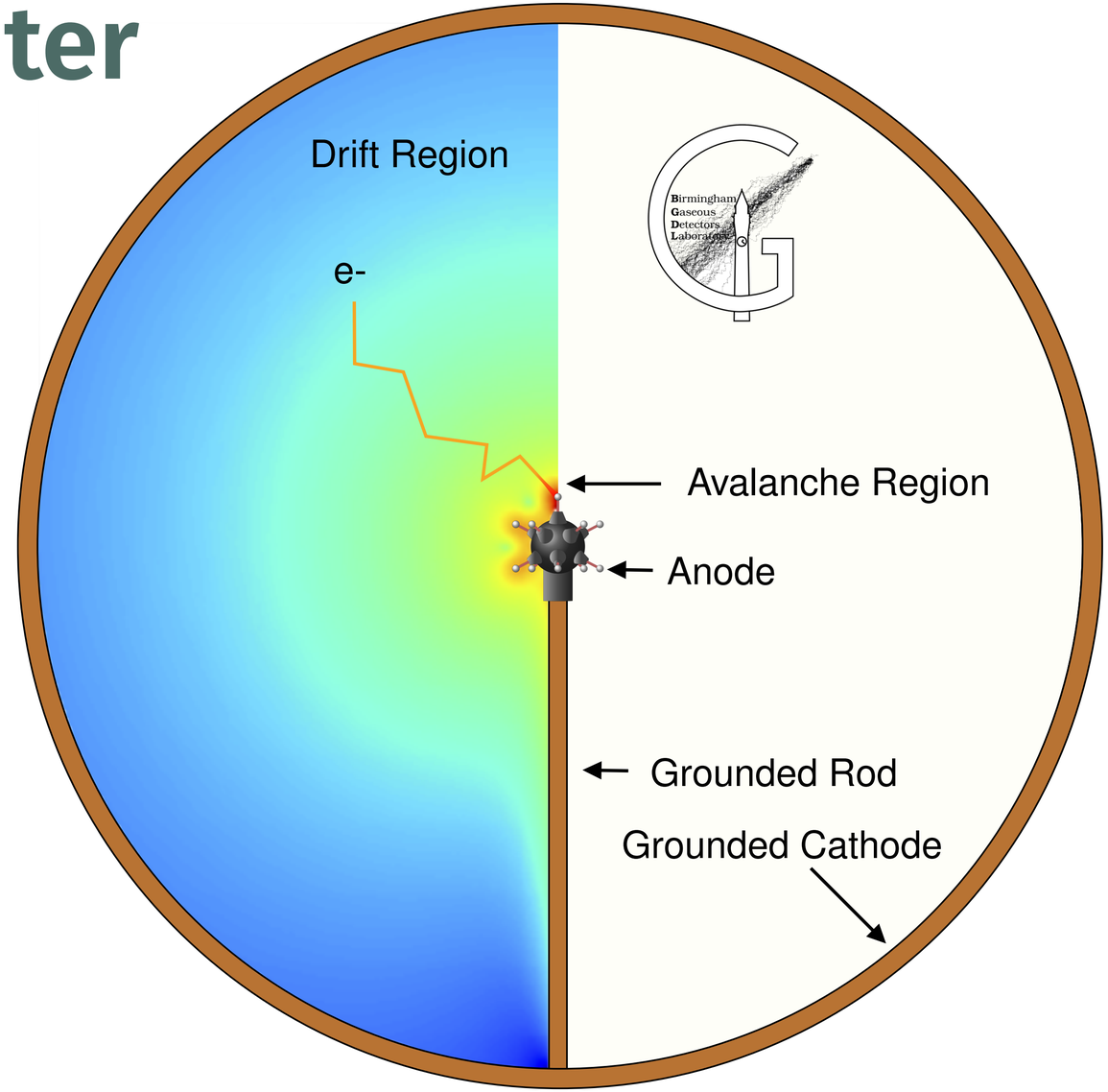
Light DM searches with a novel gaseous detector, the spherical proportional counter

Science and Technology Facilities Council

Boulby Underground Laboratory

Spherical Proportional Counter

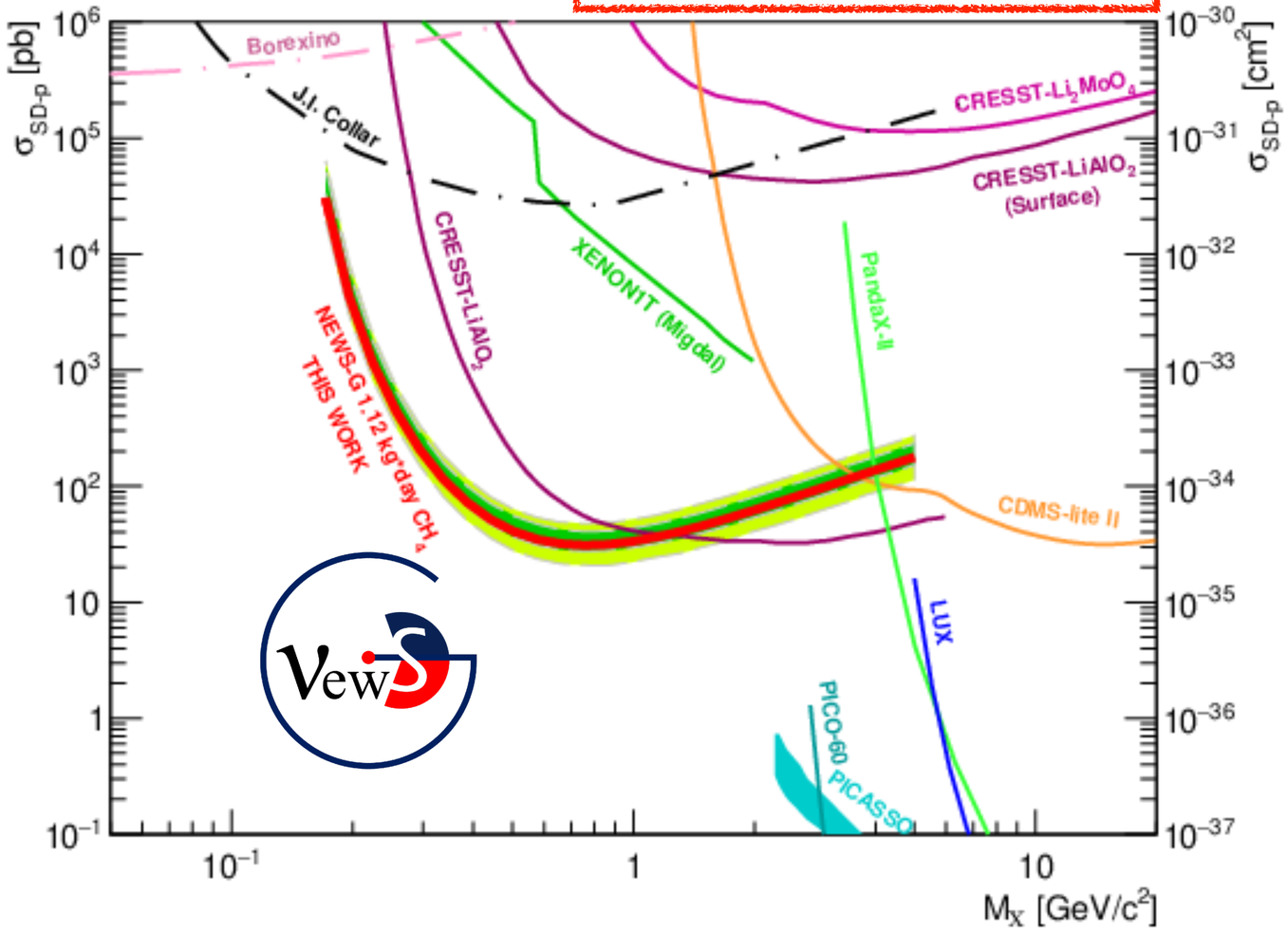
- Gaseous proportional counter
- Low capacitance, single-electron detection
- Smallest surface area to volume ratio
- Flexible choice of low-mass target nuclei
  - ➡H and C (in CH_4, i-C_4H_{10}), He, Ne, etc.
- Radiopure construction



Recent NEWS-G Results

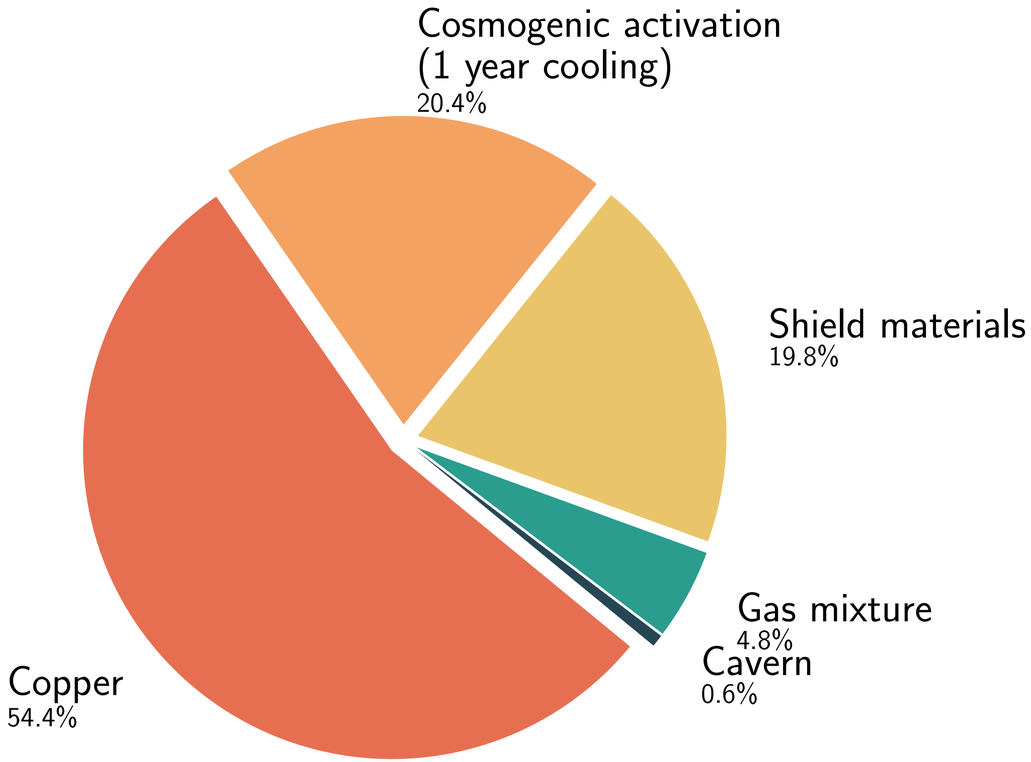
- S140 detector: ⌀140 cm detector
  - ➡99.99% pure Cu with 0.5mm electroplated radiopure Cu internal layer
- Built and tested in LSM
  - ➡First physics from commissioning data (pure CH4)
- First physics run in SNOLAB
  - ➡Analysis underway (Ne:CH4)

https://arxiv.org/abs/2407.12769

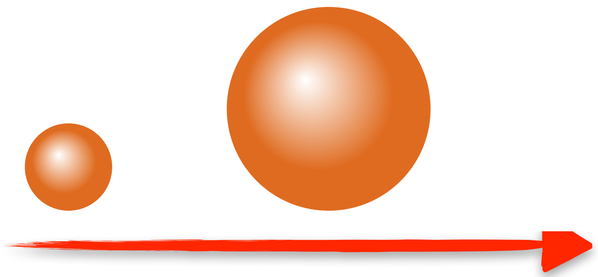


Towards the Neutrino Floor

Simulated backgrounds in SNOGLOBE



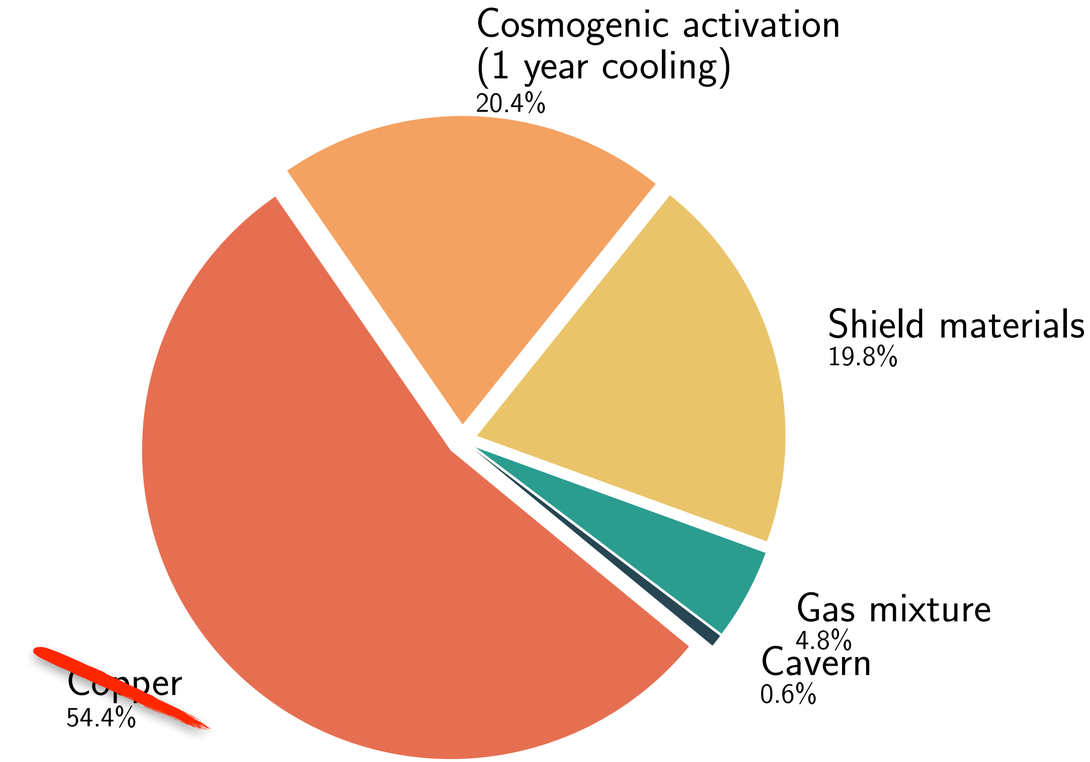
SEDINE	SNOGLOBE
∅60cm	∅140cm
NOSV Cu	99.99% Cu
	500 μm EFCu Layer



Current detectors

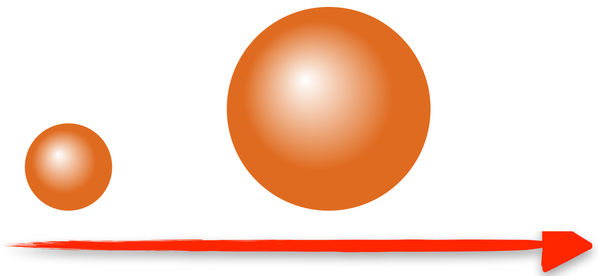
Towards the Neutrino Floor

Simulated backgrounds in SNOGLOBE



Electroforming...

SEDINE	SNOGLOBE
∅60cm	∅140cm
NOSV Cu	99.99% Cu
	500 μm EFCu Layer

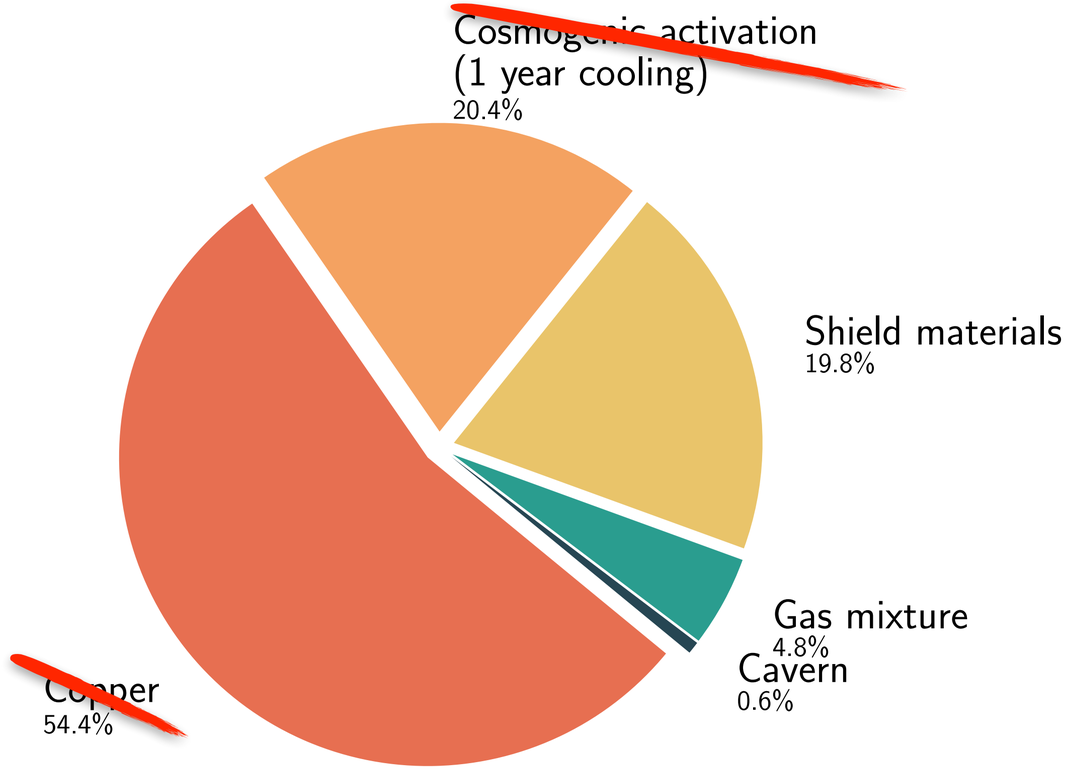


Current detectors

Towards the Neutrino Floor

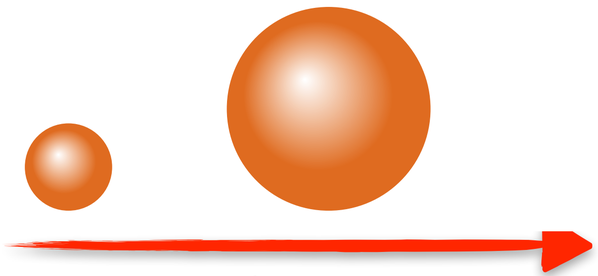
Simulated backgrounds in SNOGLOBE

...underground



Electroforming...

SEDINE	SNOGLOBE
∅60cm	∅140cm
NOSV Cu	99.99% Cu
	500 μm EFCu Layer

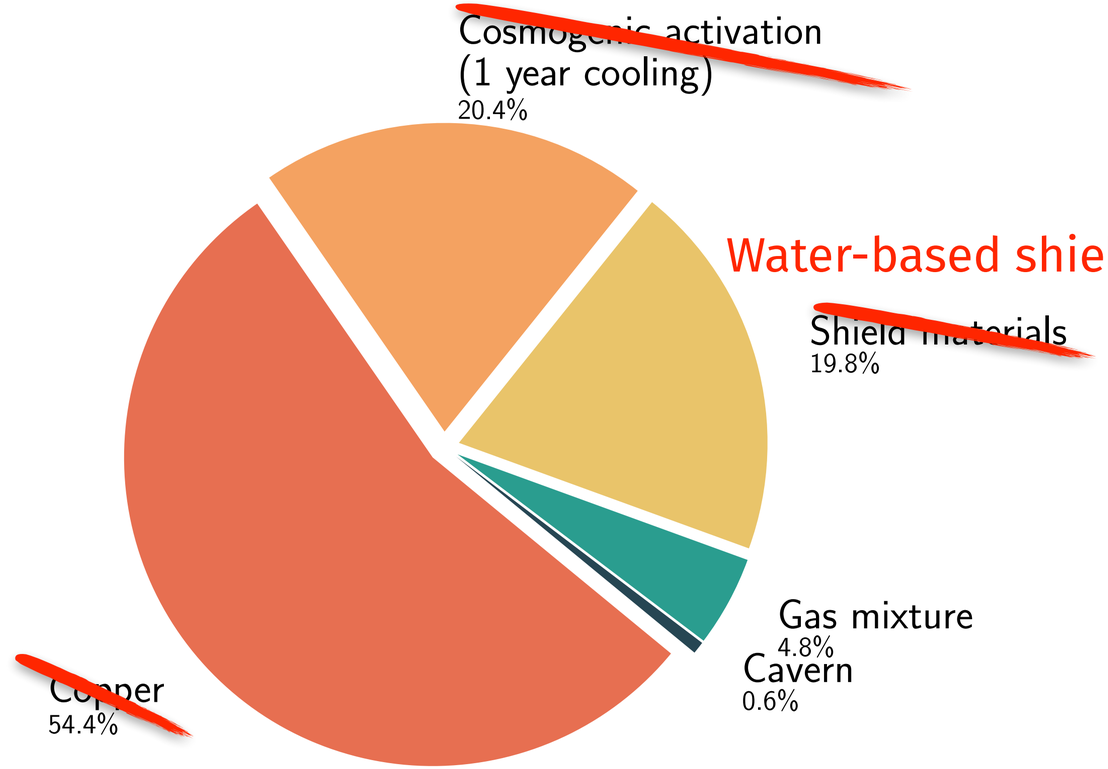


Current detectors

Towards the Neutrino Floor

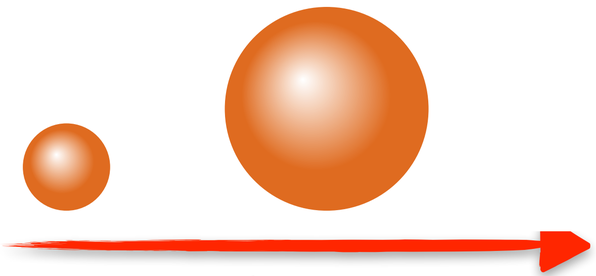
Simulated backgrounds in SNOGLOBE

...underground



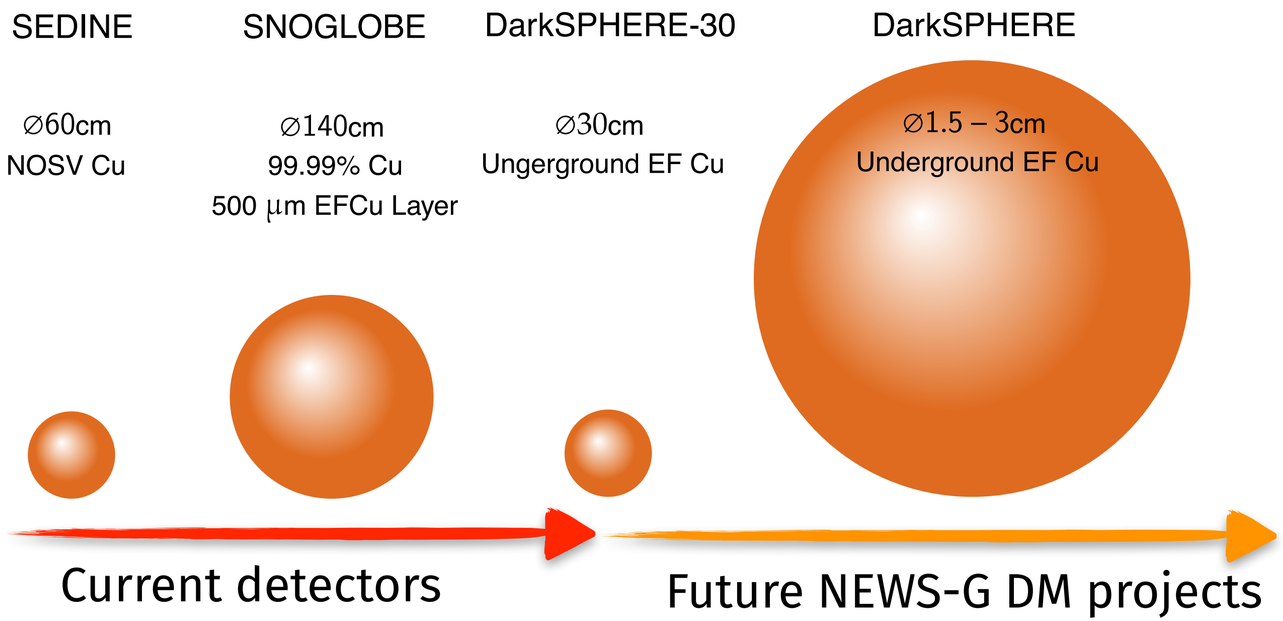
Electroforming...

SEDINE	SNOGLOBE
∅60cm	∅140cm
NOSV Cu	99.99% Cu
	500 μm EFCu Layer



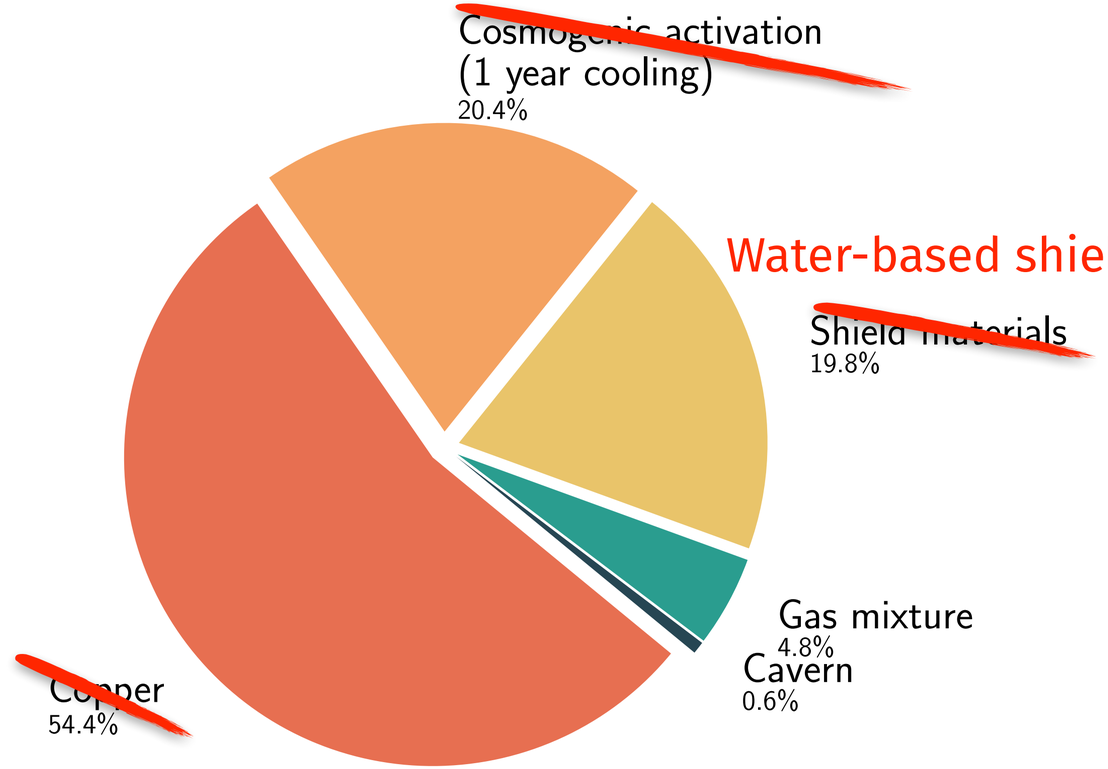
Current detectors

Towards the Neutrino Floor



Simulated backgrounds in SNOGLOBE

...underground



Electroforming...

Towards the Neutrino Floor

PHYSICAL REVIEW D **108,** 112006 (2023)

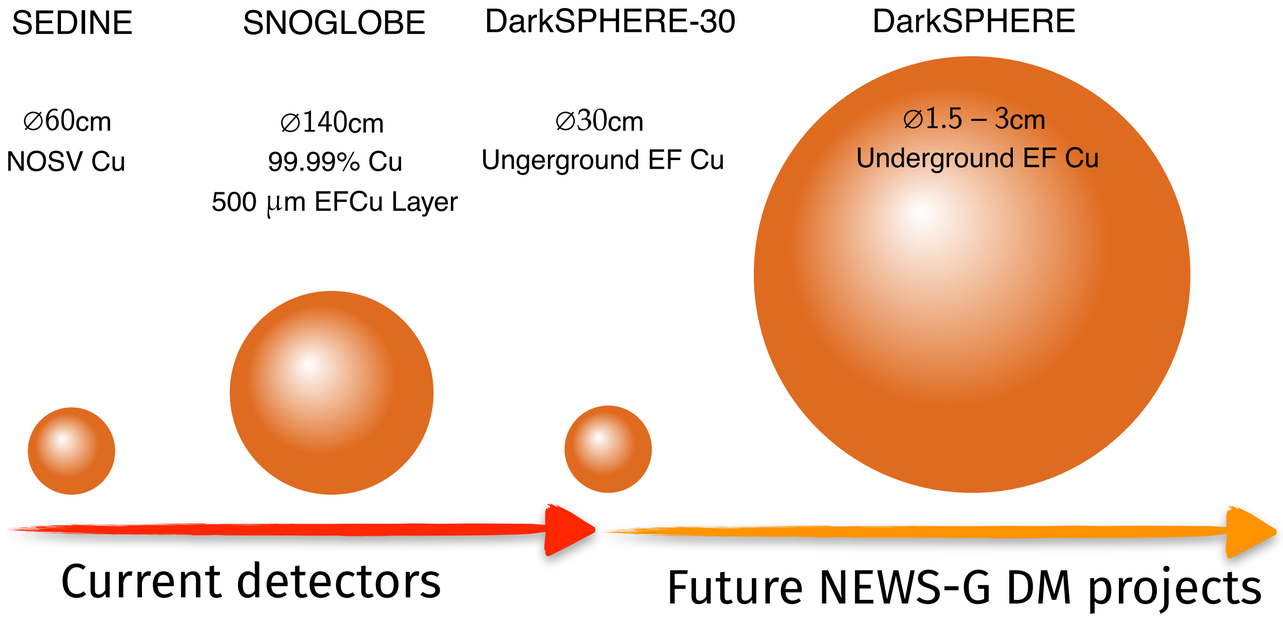
Phys.Rev.D 108 (2023) 11, 112006

Exploring light dark matter with the DarkSPHERE spherical proportional counter electroformed underground at the Boulby Underground Laboratory

L. Balogh,[1] C. Beaufort,[2] M. Chapellier,[3] E. C. Corcoran,[4] J.-M. Coquillat,[3] A. Dastgheibi-Fard,[2] Y. Deng,[5] D. Durnford,[5] C. Garrah,[5] G. Gerbier,[3] I. Giomataris,[6] G. Giroux,[3] P. Gorel,[7] M. Gros,[6] P. Gros,[3] O. Guillaudin,[2] E. W. Hoppe,[8] I. Katsioulas,[9] F. Kelly,[4] P. Knights,[9,*] P. Lautridou,[10] I. Manthos,[9] R. D. Martin,[3] J. Matthews,[9] J.-F. Muraz,[2] T. Neep,[9] K. Nikolopoulos,[9] P. O'Brien,[5] M.-C. Piro,[5] N. Rowe,[3] D. Santos,[2] G. Savvidis,[3] I. Savvidis,[11] F. Vazquez de Sola Fernandez,[10] R. Ward[9]

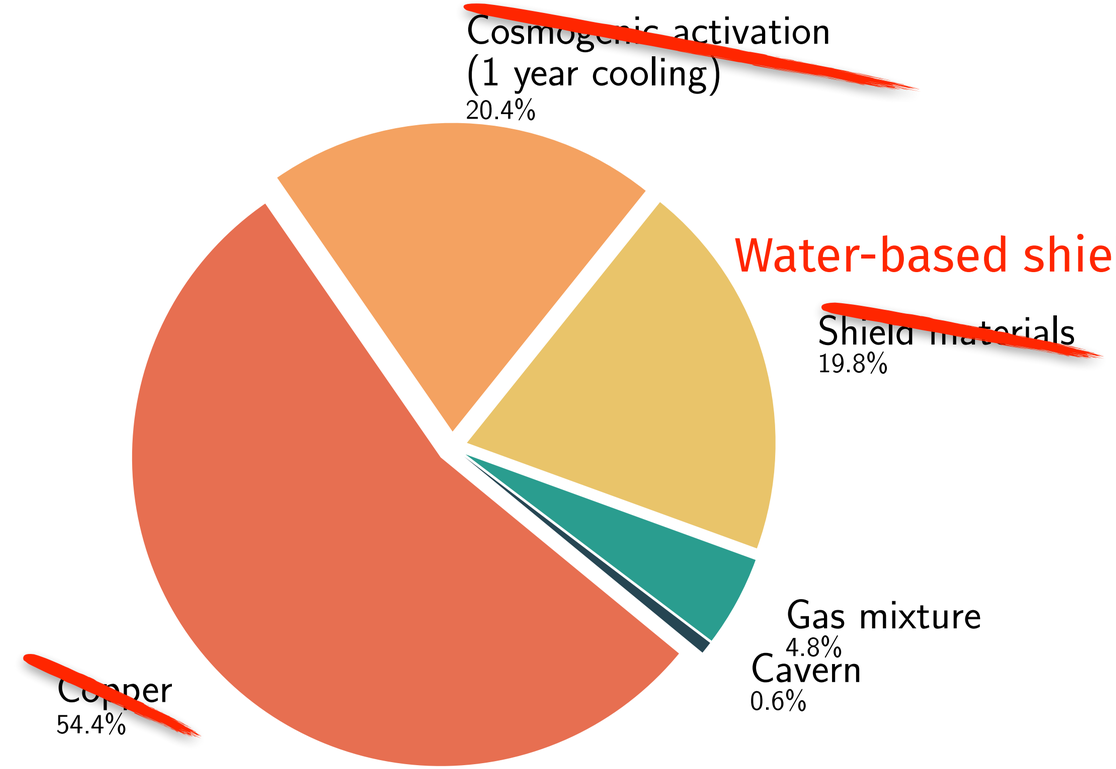
(NEWS-G Collaboration)

E. Banks,[12] L. Hamaide,[13] C. McCabe,[13] K. Mimasu,[13] and S. Paling[12]



Simulated backgrounds in SNOGLOBE

...underground



Electroforming...

Towards the Neutrino Floor

PHYSICAL REVIEW D **108,** 112006 (2023)

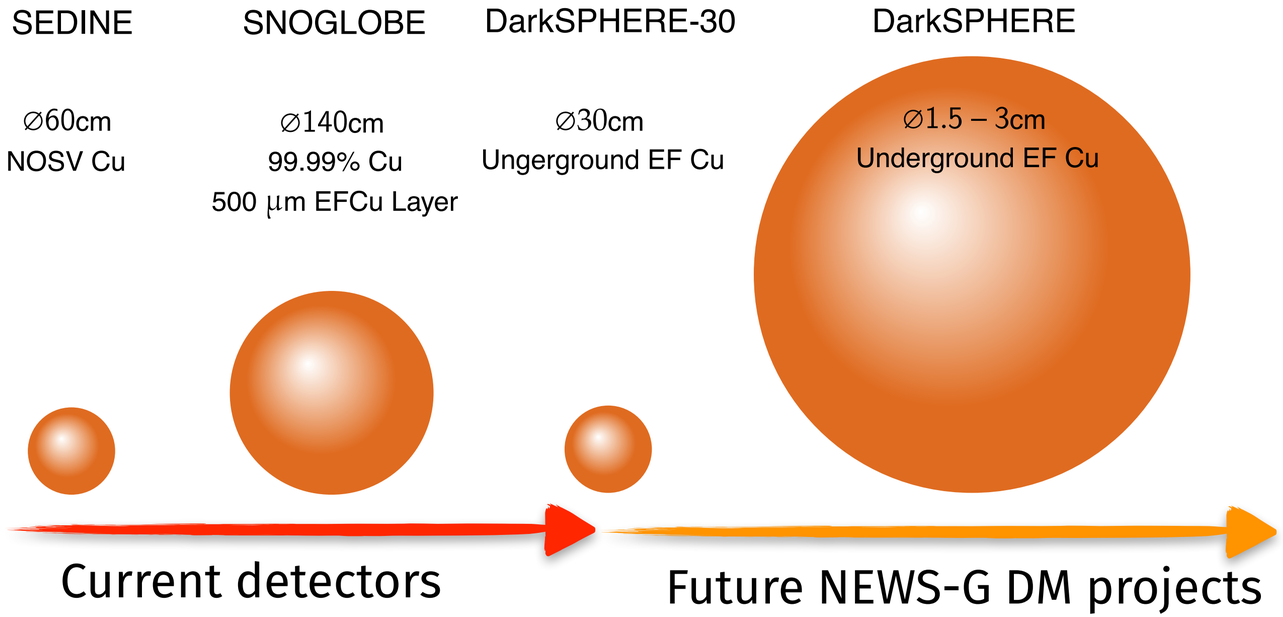
Phys.Rev.D 108 (2023) 11, 112006

Exploring light dark matter with the DarkSPHERE spherical proportional counter electroformed underground at the Boulby Underground Laboratory

L. Balogh,[1] C. Beaufort,[2] M. Chapellier,[3] E. C. Corcoran,[4] J.-M. Coquillat,[3] A. Dastgheibi-Fard,[2] Y. Deng,[5] D. Durnford,[5] C. Garrah,[5] G. Gerbier,[3] I. Giomataris,[6] G. Giroux,[3] P. Gorel,[7] M. Gros,[6] P. Gros,[3] O. Guillaudin,[2] E. W. Hoppe,[8] I. Katsioulas,[9] F. Kelly,[4] P. Knights,[9,*] P. Lautridou,[10] I. Manthos,[9] R. D. Martin,[3] J. Matthews,[9] J.-F. Muraz,[2] T. Neep,[9] K. Nikolopoulos,[9] P. O'Brien,[5] M.-C. Piro,[5] N. Rowe,[3] D. Santos,[2] G. Savvidis,[3] I. Savvidis,[11] F. Vazquez de Sola Fernandez,[10] R. Ward[9]

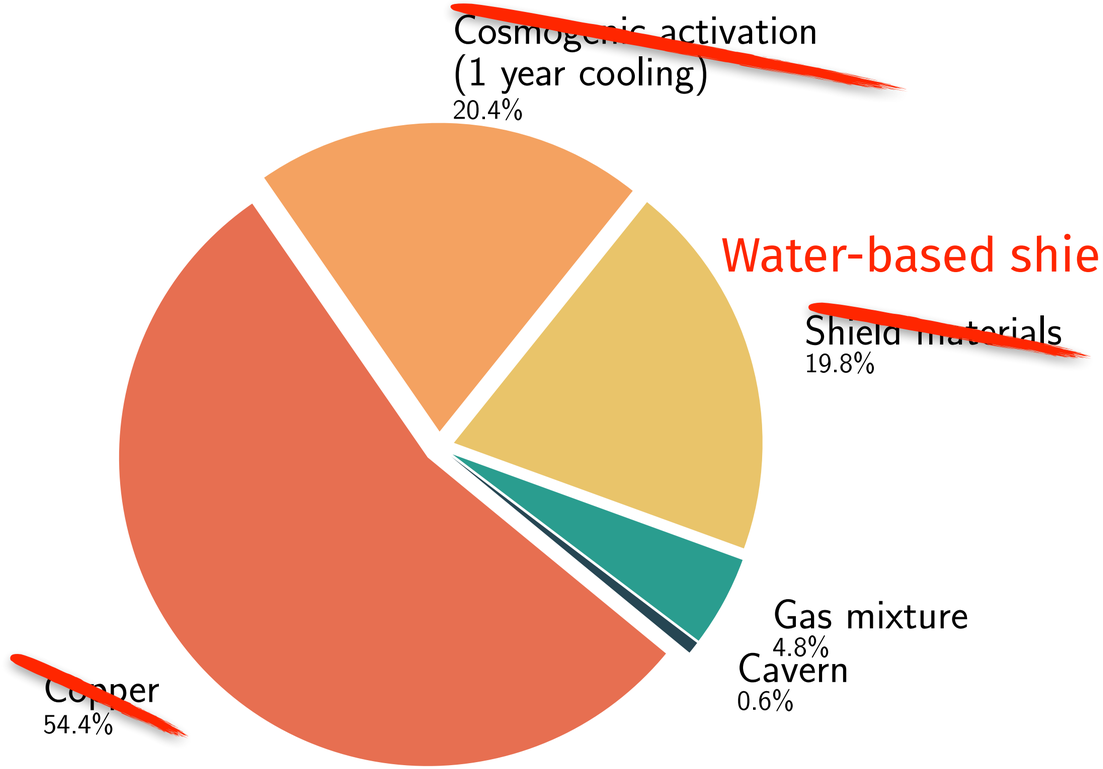
(NEWS-G Collaboration)

E. Banks,[12] L. Hamaide,[13] C. McCabe,[13] K. Mimasu,[13] and S. Paling[12]



Simulated backgrounds in SNOGLOBE

...underground



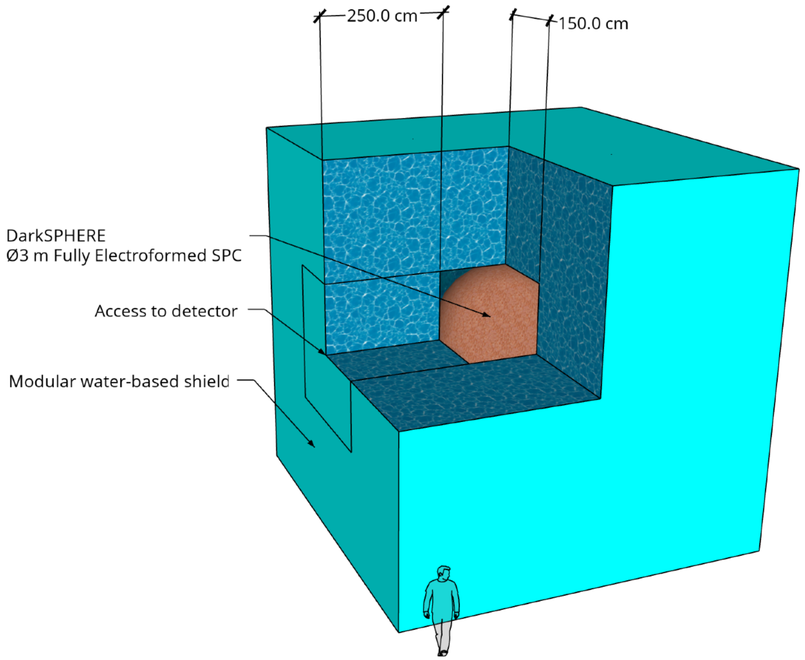
Electroforming...

- Recent proposal from team from 9 UK institutes
  - ➡UK-led direct DM search in UK, benefitting from international NEWS-G experience, completed R&D, and wider DM experience

DarkSPHERE in Boulby

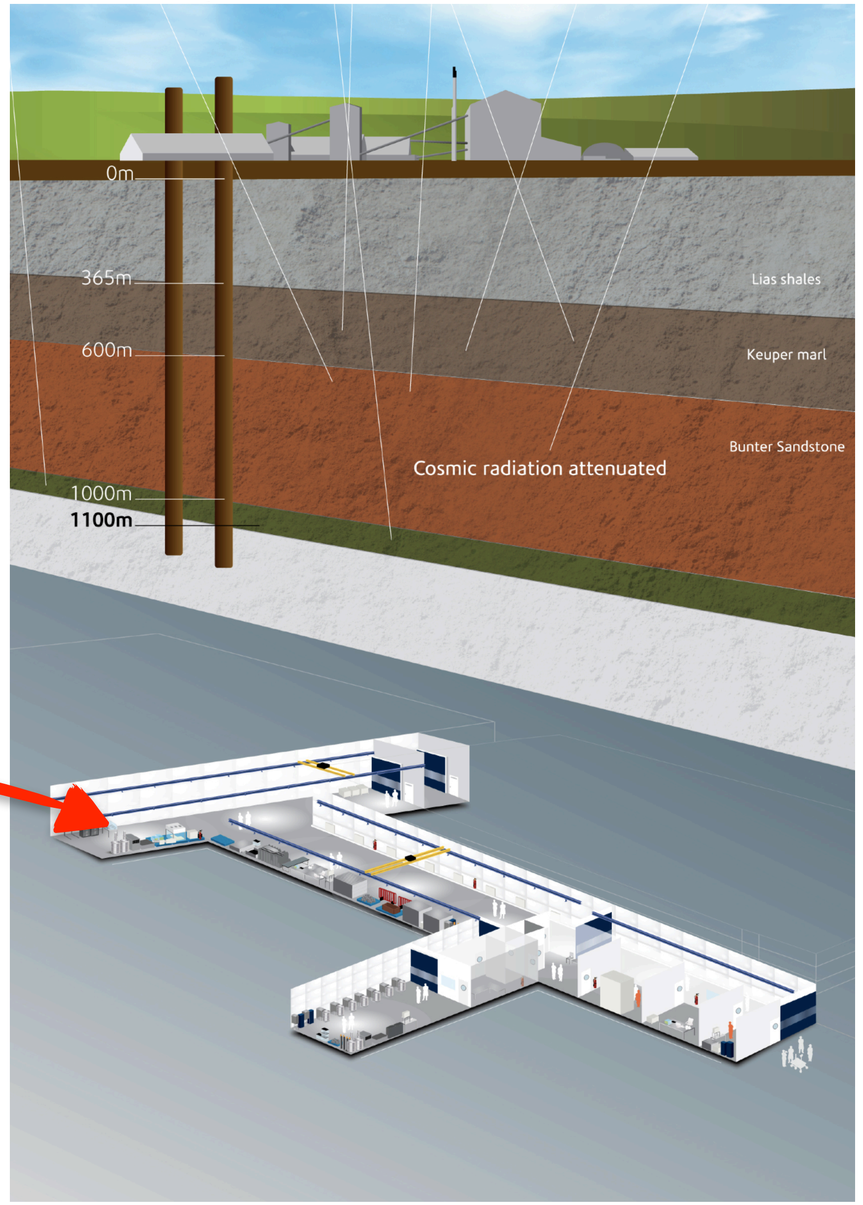
Science and Technology Facilities Council
Boulby Underground Laboratory

- DarkSPHERE will use a modular water-based shield
- A pure water shield is sufficient for background goal of **0.01 event/keV/kg/day** in ROI

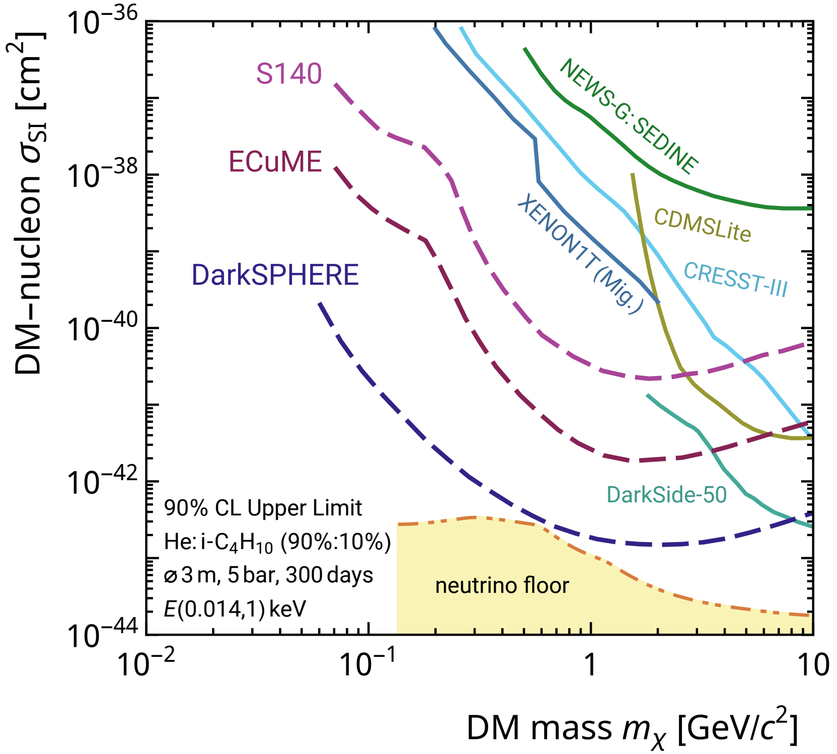


Conceptual design fits in Large Experiment Cavern

^{222}Rn ~3 Bq/m^3 *P. Scovell, DMUK 2019*
μ ~4×10^{-8} /cm^2/s *NIMA 511 (2003) 347-353*

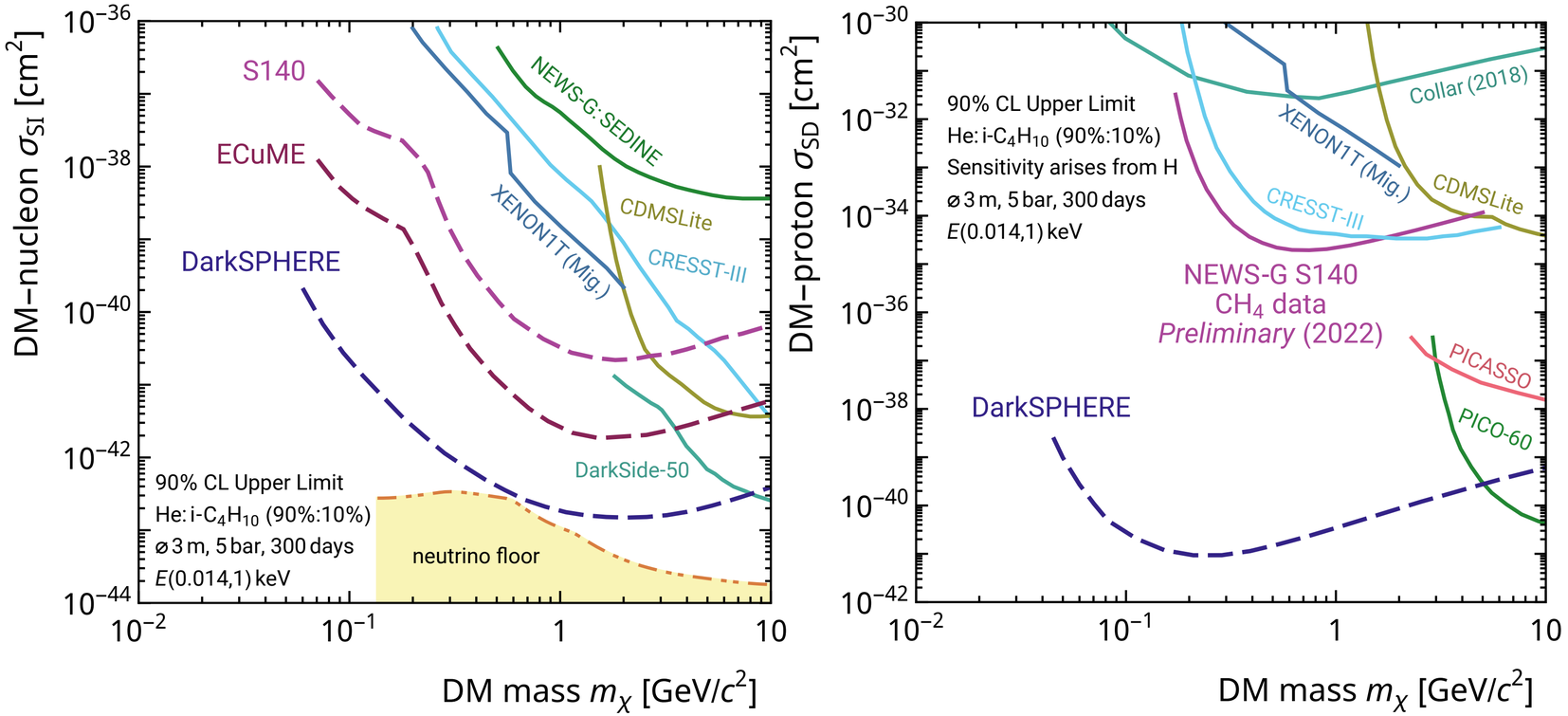


DarkSPHERE (⌀3m) Physics Potential



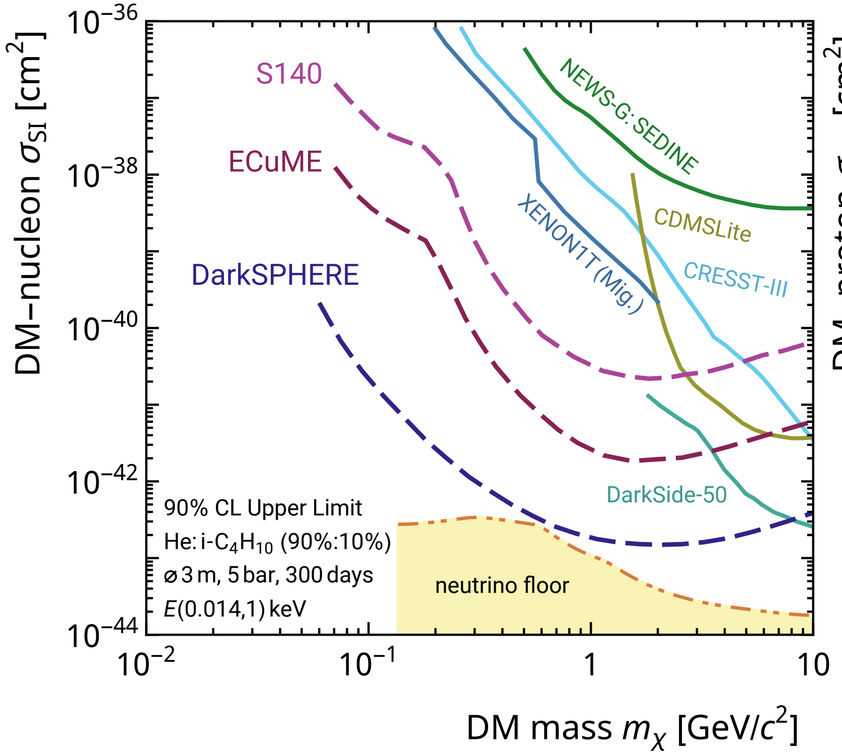
- **‘Neutrino-floor’ reaching potential** in DM-nucleon SI interactions
- **World-leading** potential in SD interactions through natural-abundance H and C isotopes
- ⌀30cm prototype in Boulby in a DarkSPHERE-like shield will have world-leading sensitivity

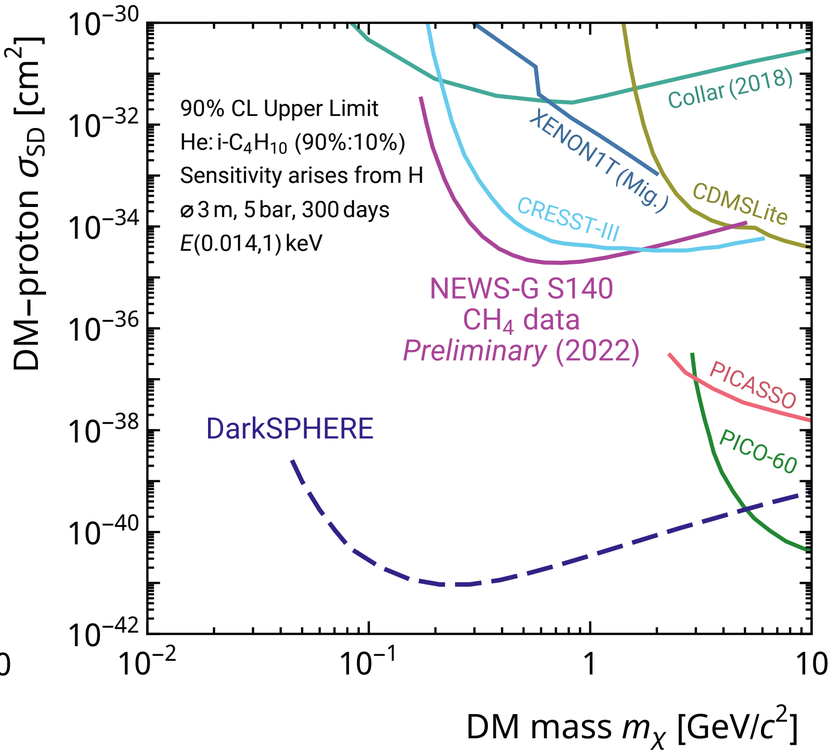
DarkSPHERE (⌀3m) Physics Potential

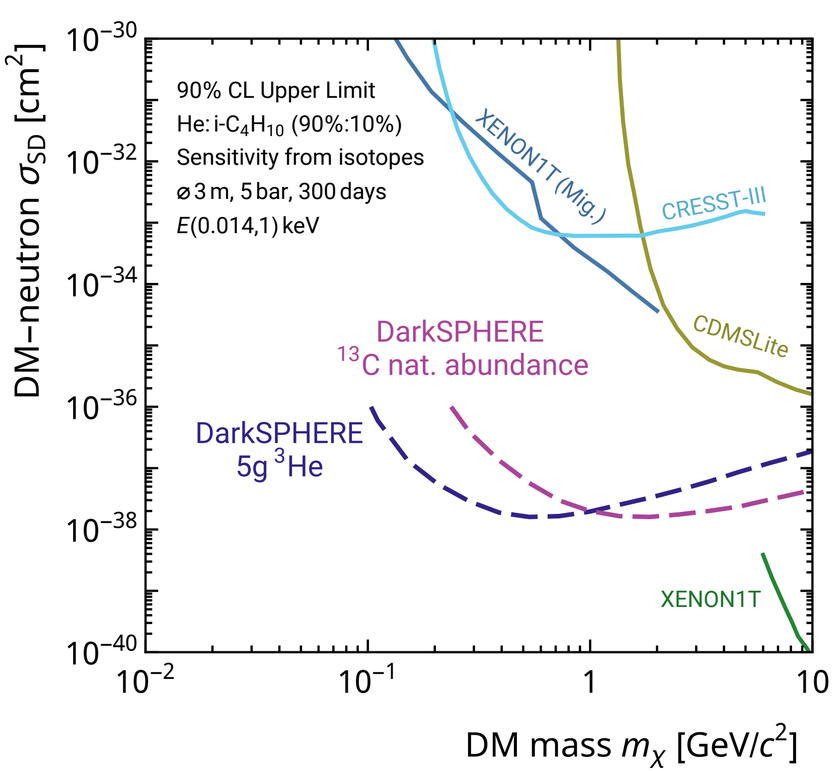


- **'Neutrino-floor' reaching potential** in DM-nucleon SI interactions
- **World-leading** potential in SD interactions through natural-abundance H and C isotopes
- ⌀30cm prototype in Boulby in a DarkSPHERE-like shield will have world-leading sensitivity

DarkSPHERE (⌀3m) Physics Potential

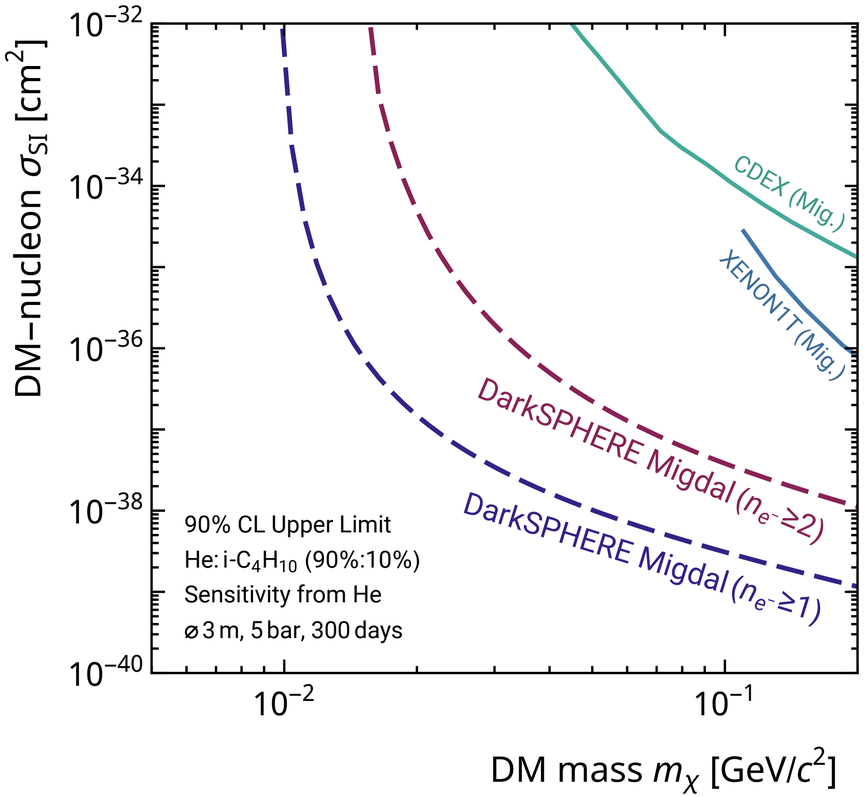






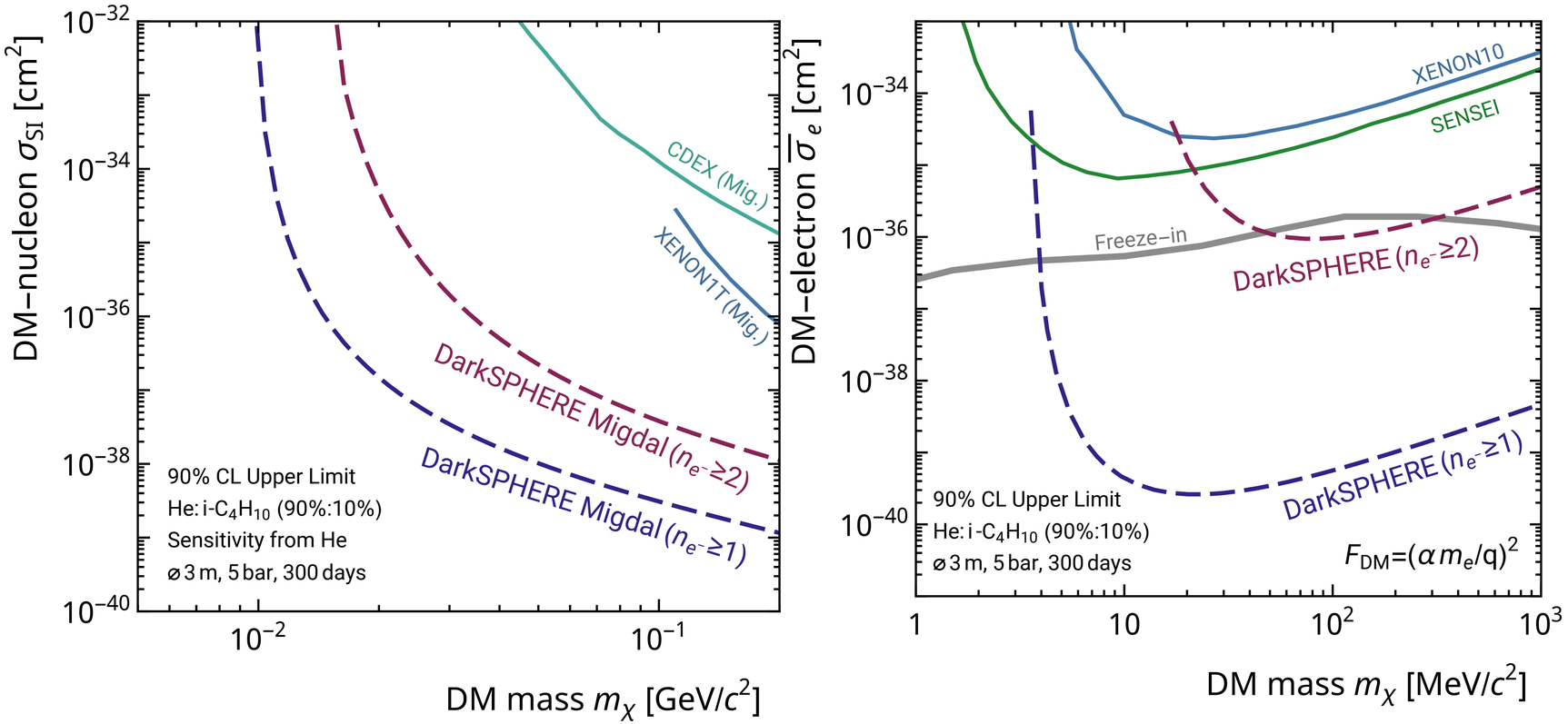
- **‘Neutrino-floor’ reaching potential** in DM-nucleon SI interactions
- **World-leading** potential in SD interactions through natural-abundance H and C isotopes
- ⌀30cm prototype in Boulby in a DarkSPHERE-like shield will have world-leading sensitivity

DarkSPHERE (⌀3m) Physics Potential



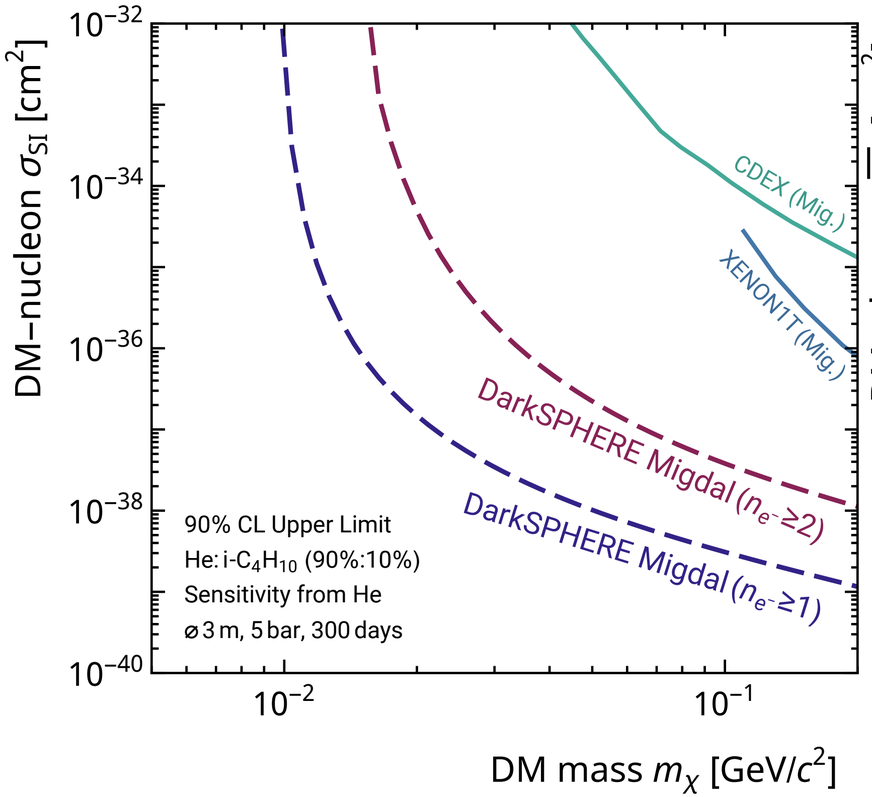
- Enhanced sensitivity through **MIGDAL effect** in nuclear scattering
- Sensitivity to electron scattering through low threshold
- Large sphere is also ideal shape to study more **exotic candidates**

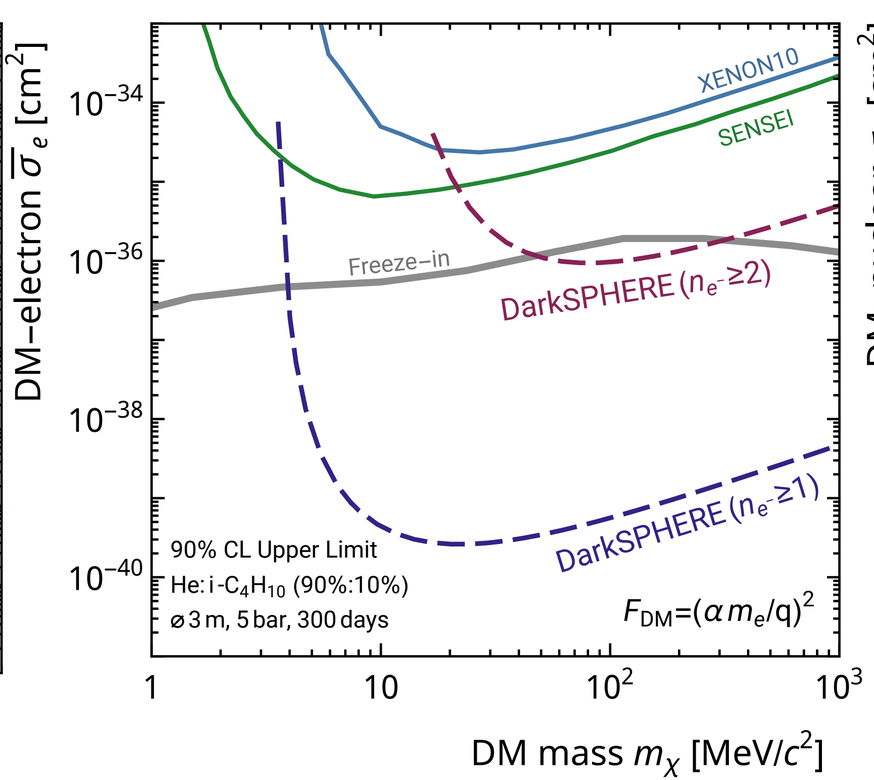
DarkSPHERE (⌀3m) Physics Potential

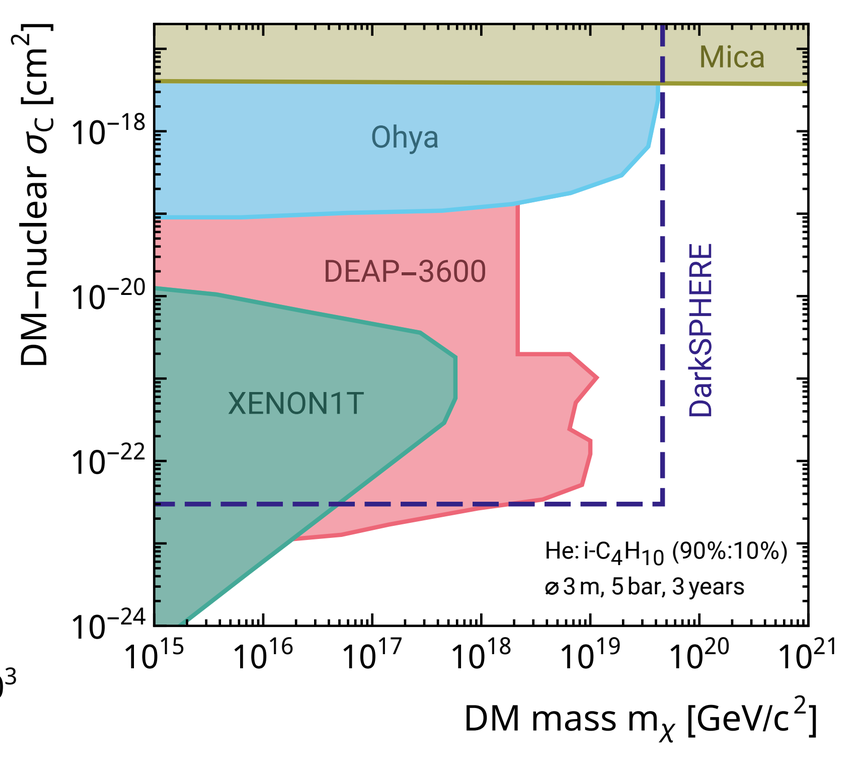


- Enhanced sensitivity through **MIGDAL effect** in nuclear scattering
- Sensitivity to electron scattering through low threshold
- Large sphere is also ideal shape to study more **exotic candidates**

DarkSPHERE (⌀3m) Physics Potential



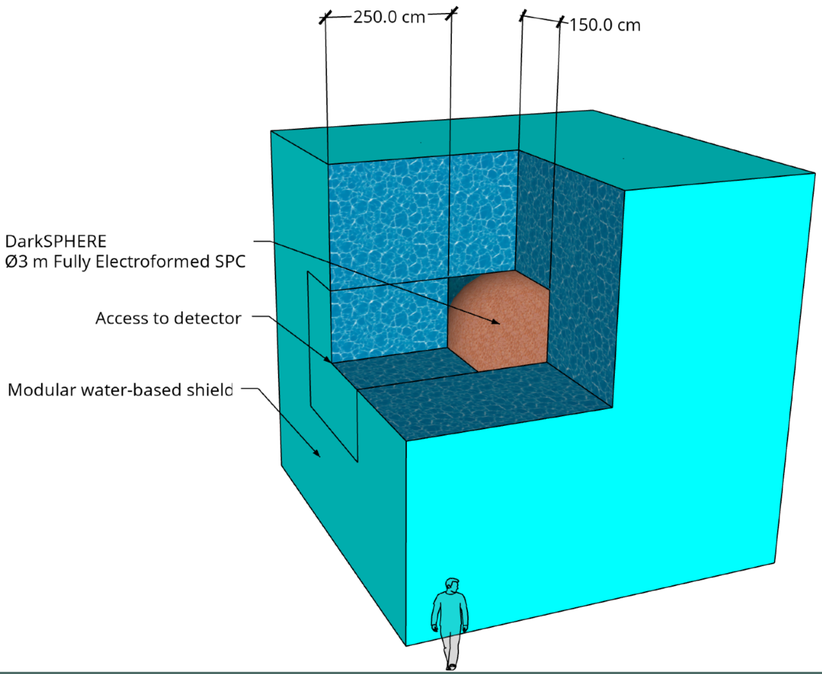


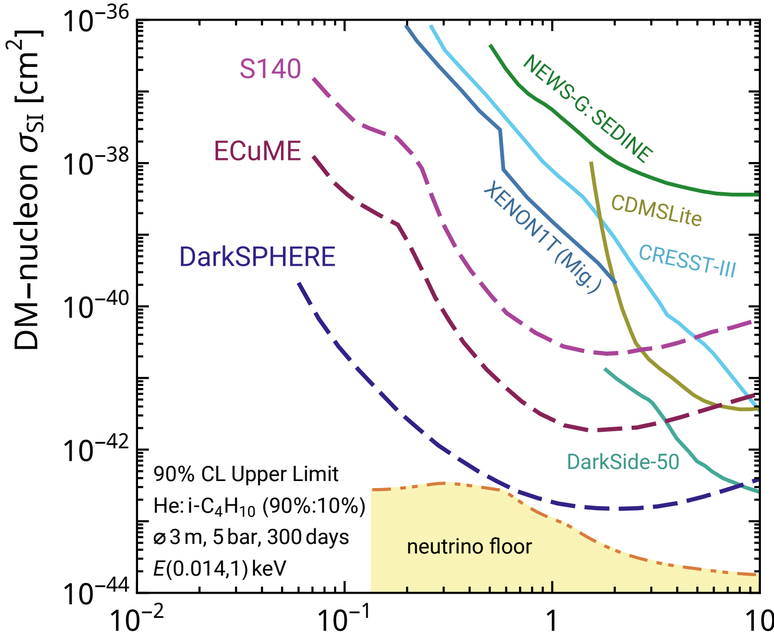


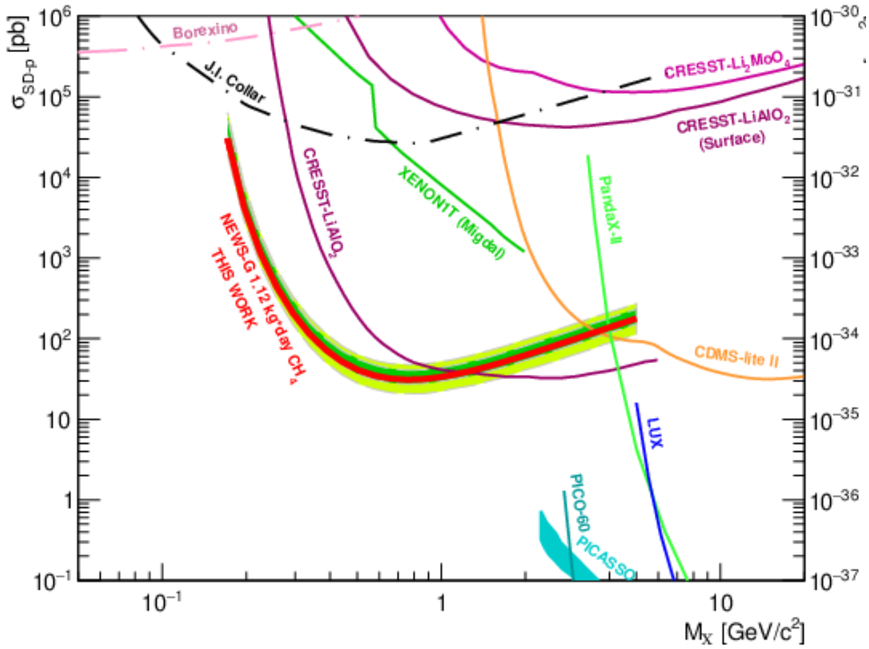
- Enhanced sensitivity through **MIGDAL effect** in nuclear scattering
- Sensitivity to electron scattering through low threshold
- Large sphere is also ideal shape to study more **exotic candidates**

Summary

- Spherical proportional counters already employed for light-DM searches
- Full detector electroformation will overcome main BG
- **DarkSPHERE** proposed for Boulby's existing space
  - ➡World-leading physics potential in multiple interactions
  - ➡Scientific and technological complementarity with future DM experiments



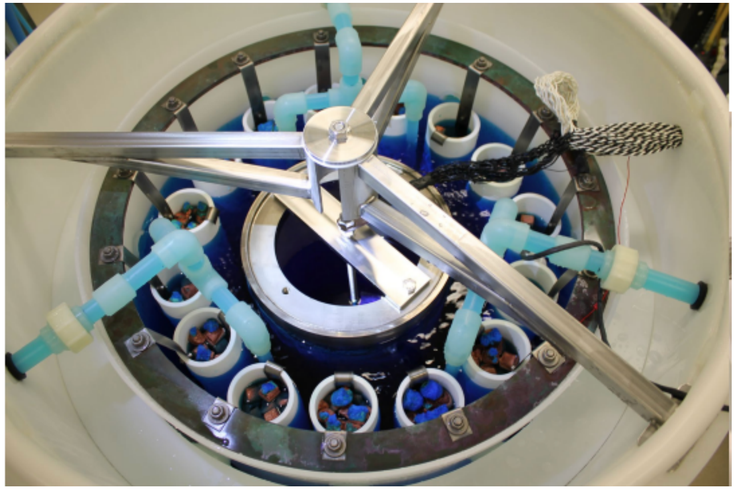




EFCu in Boulby

- ECuME project: R&D completed for ⌀140cm detector + scale model
- STFC funding for an ultra-pure EFCu facility underground in Boulby
  - ➡Currently under construction
- EFCu facility to be employed by other efforts (e.g. **XLZD**)

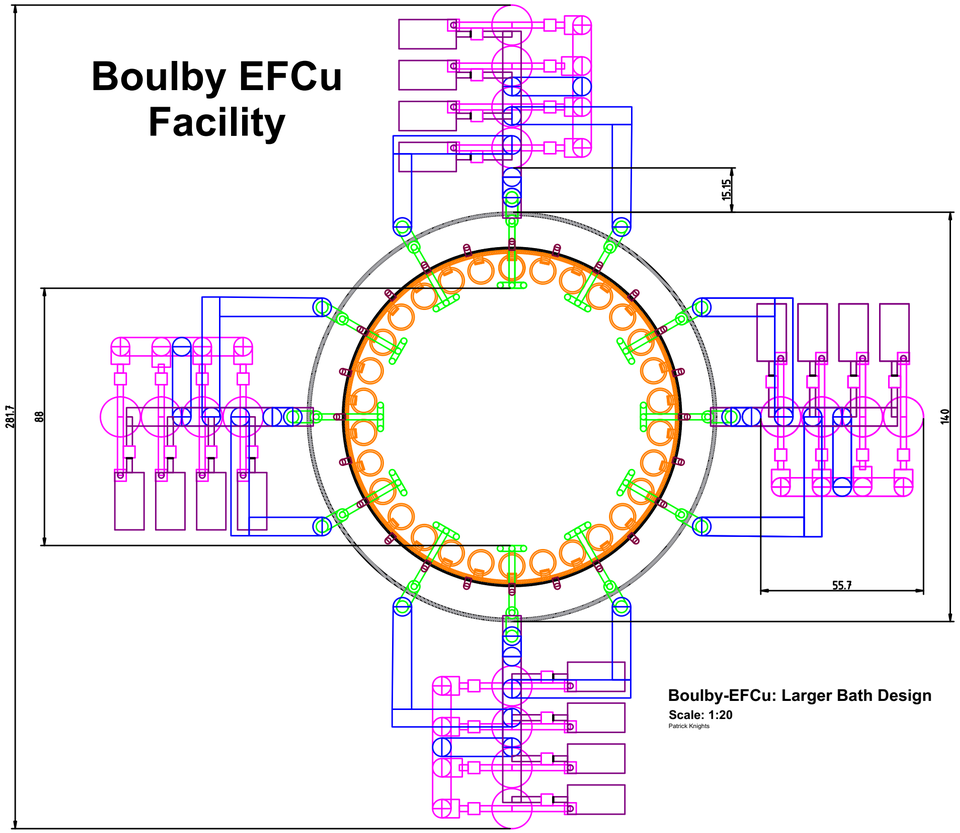
Example electroforming bath
at Pacific Northwest National Laboratory



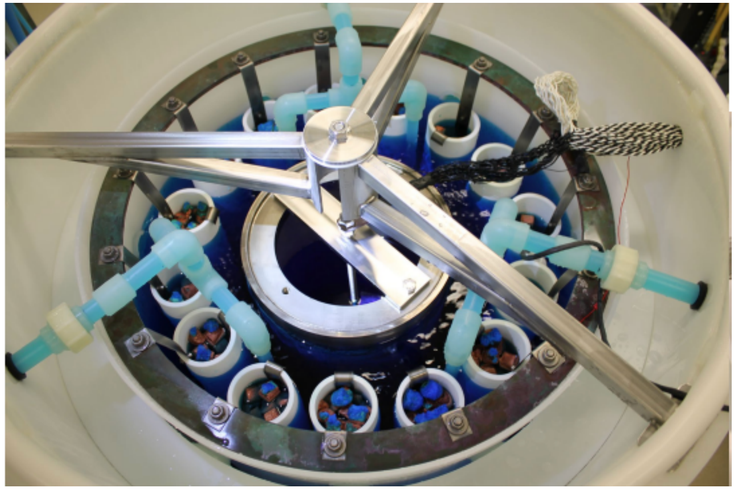
Credit: E W Hoppe, PNNL

EFCu in Boulby

- ECuME project: R&D completed for ⌀140cm detector + scale model
- STFC funding for an ultra-pure EFCu facility underground in Boulby
  - ➡Currently under construction
- EFCu facility to be employed by other efforts (e.g. **XLZD**)



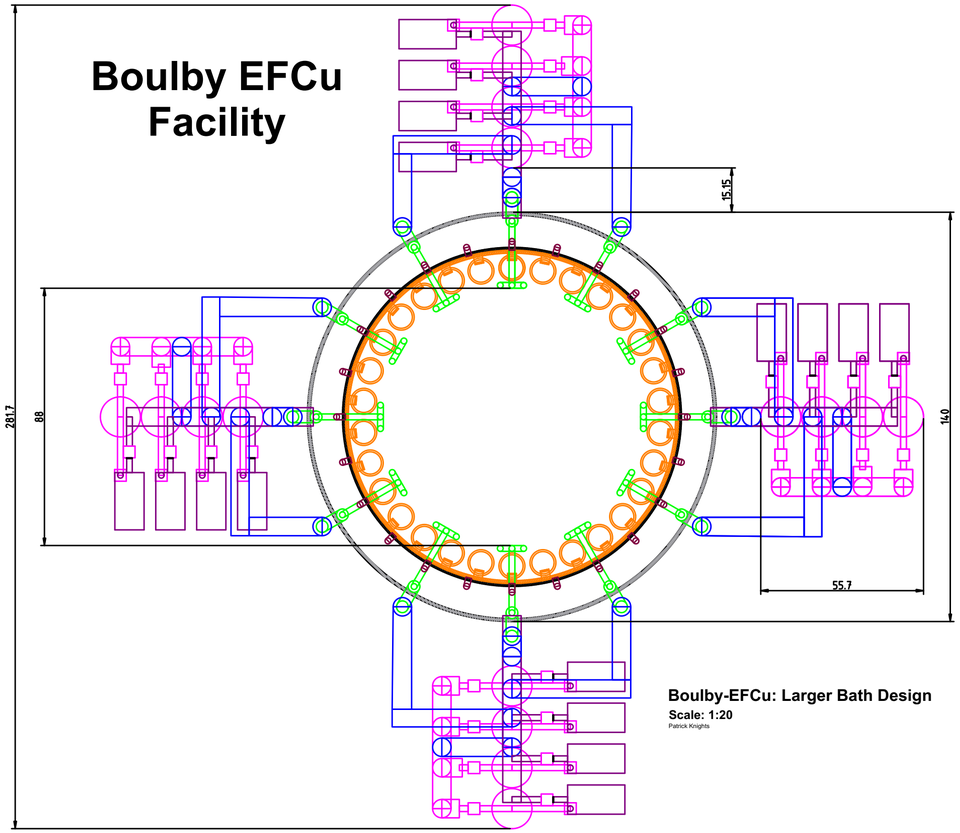
Example electroforming bath at Pacific Northwest National Laboratory



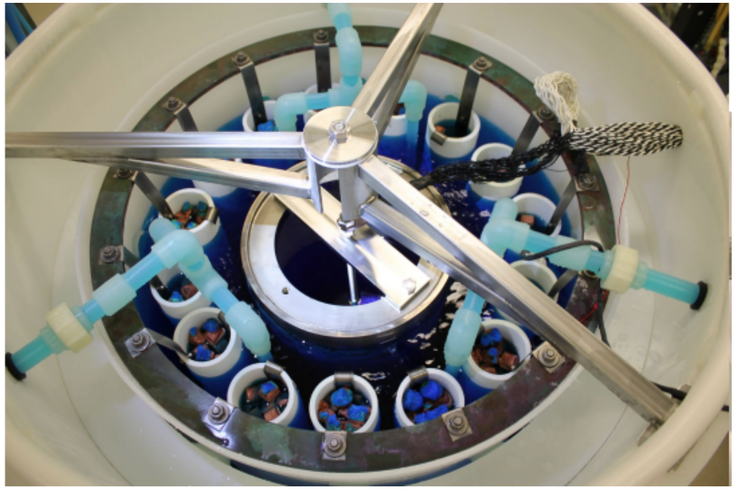
Credit: E W Hoppe, PNNL

EFCu in Boulby

- ECuME project: R&D completed for ⌀140cm detector + scale model
- STFC funding for an ultra-pure EFCu facility underground in Boulby
  - ➡Currently under construction
- EFCu facility to be employed by other efforts (e.g. **XLZD**)



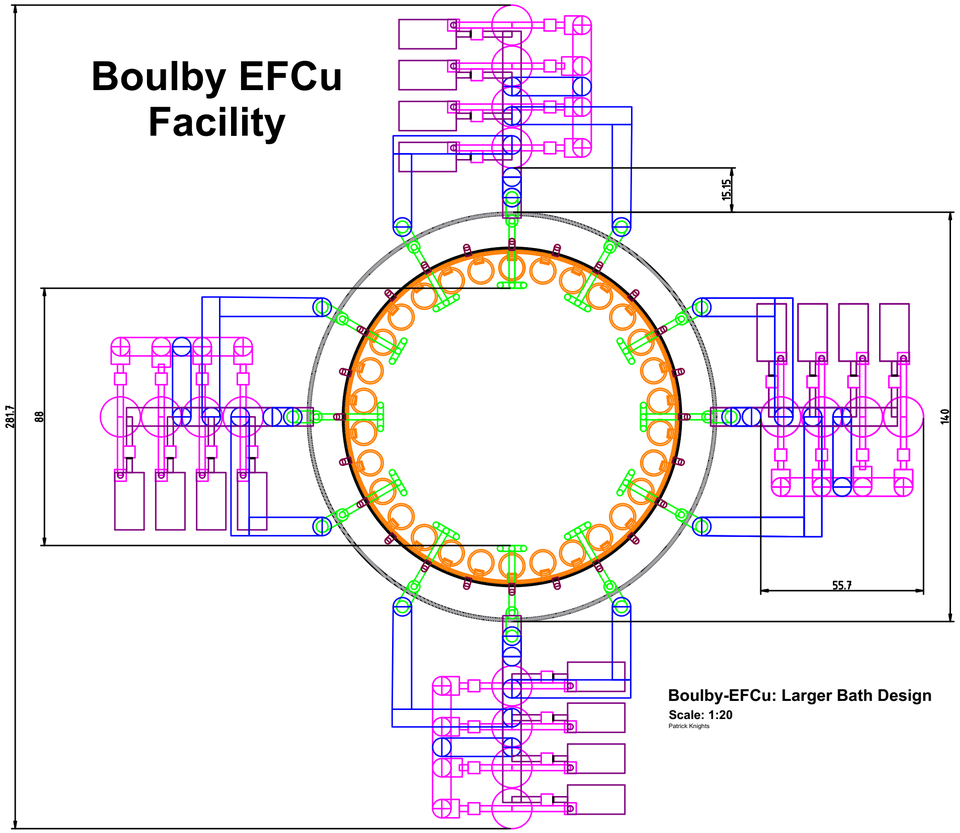
Example electroforming bath at Pacific Northwest National Laboratory



Credit: E W Hoppe, PNNL

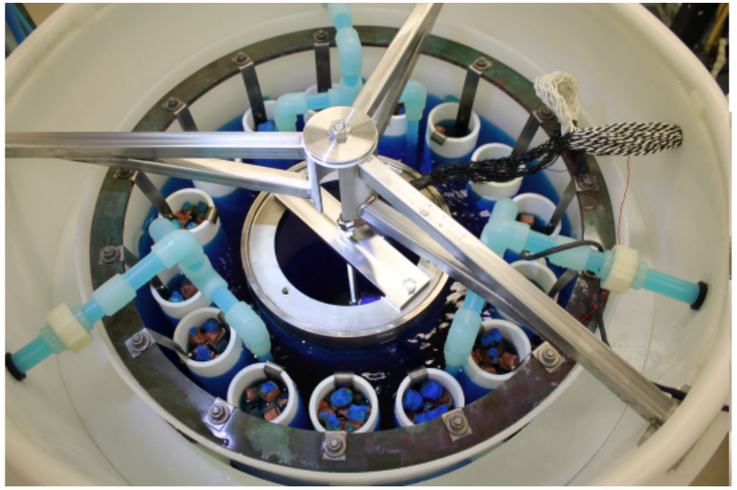
EFCu in Boulby

- ECuME project: R&D completed for ⌀140cm detector + scale model
- STFC funding for an ultra-pure EFCu facility underground in Boulby
  - ➡Currently under construction
- EFCu facility to be employed by other efforts (e.g. **XLZD**)



Construction of bath underway

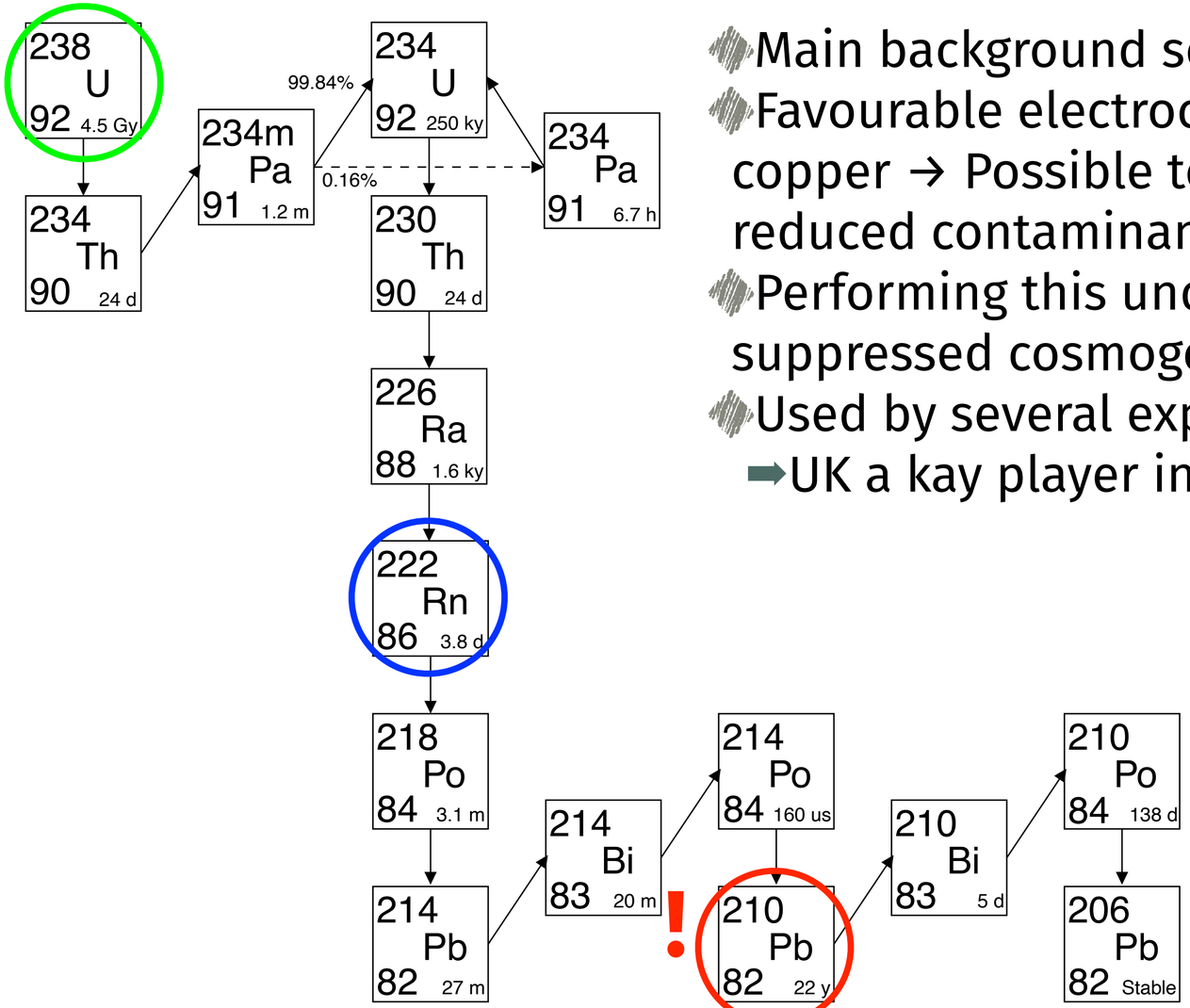
Example electroforming bath at Pacific Northwest National Laboratory



Credit: E W Hoppe, PNNL

First EFCu test in Boulby

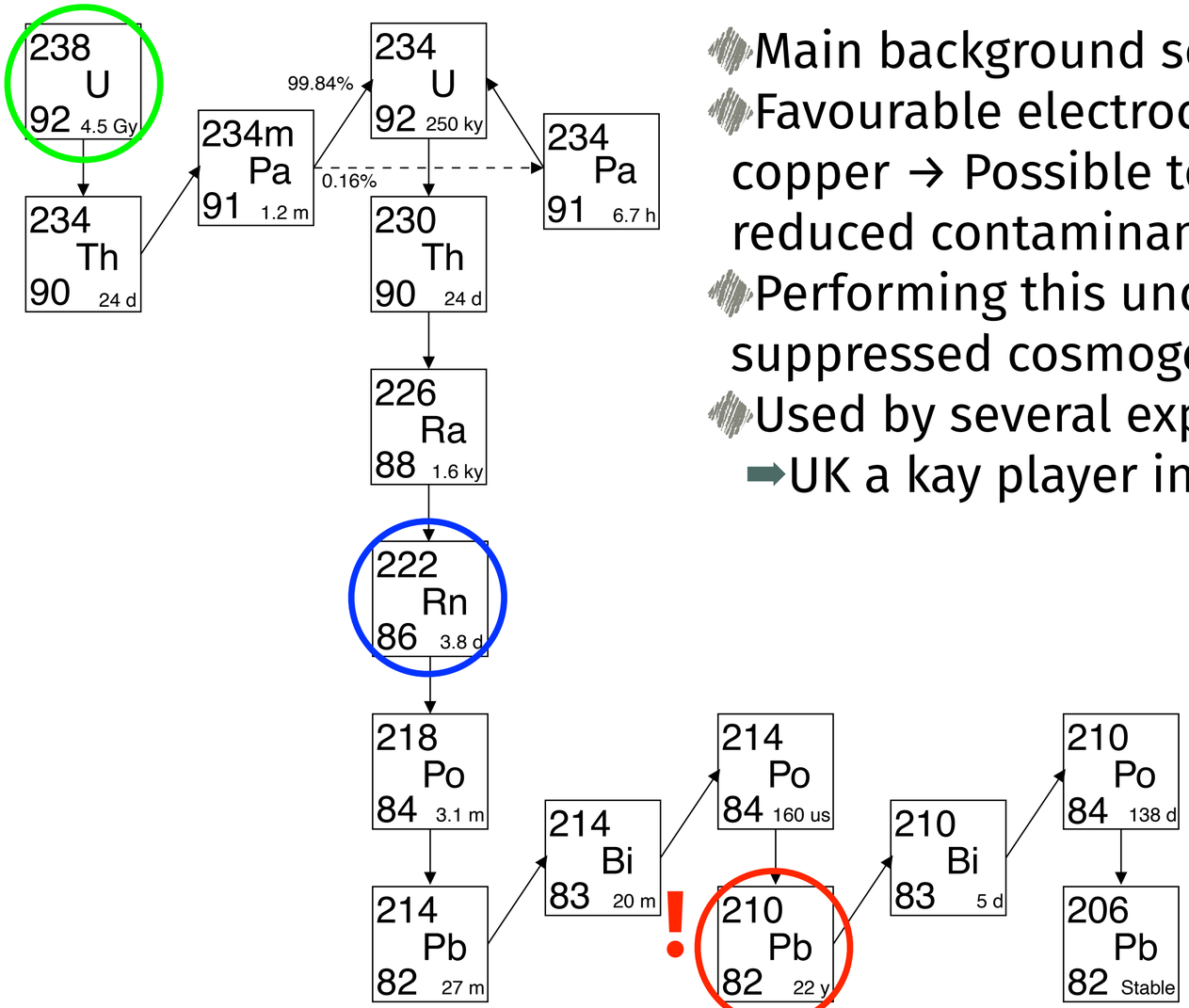
Ultra-Pure Cu Electroforming



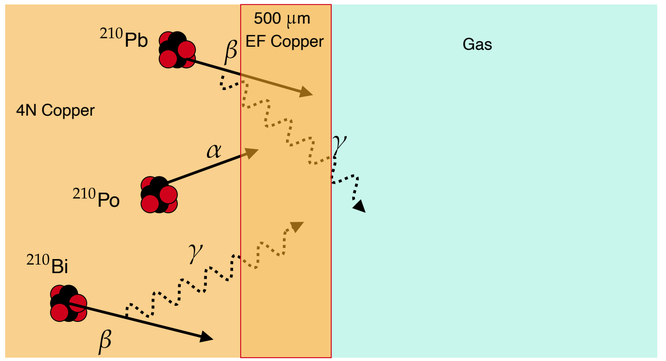
- Main background source Cu detector
- Favourable electrochemical properties of copper → Possible to produce copper with reduced contaminants (e.g. U, Th, K, etc.)
- Performing this underground → suppressed cosmogenic activation
- Used by several experiments, e.g. NEWS-G
  - ➡UK a kay player in this

Nucl.Instrum.Meth.A 988 (2021) 164844

Ultra-Pure Cu Electroforming

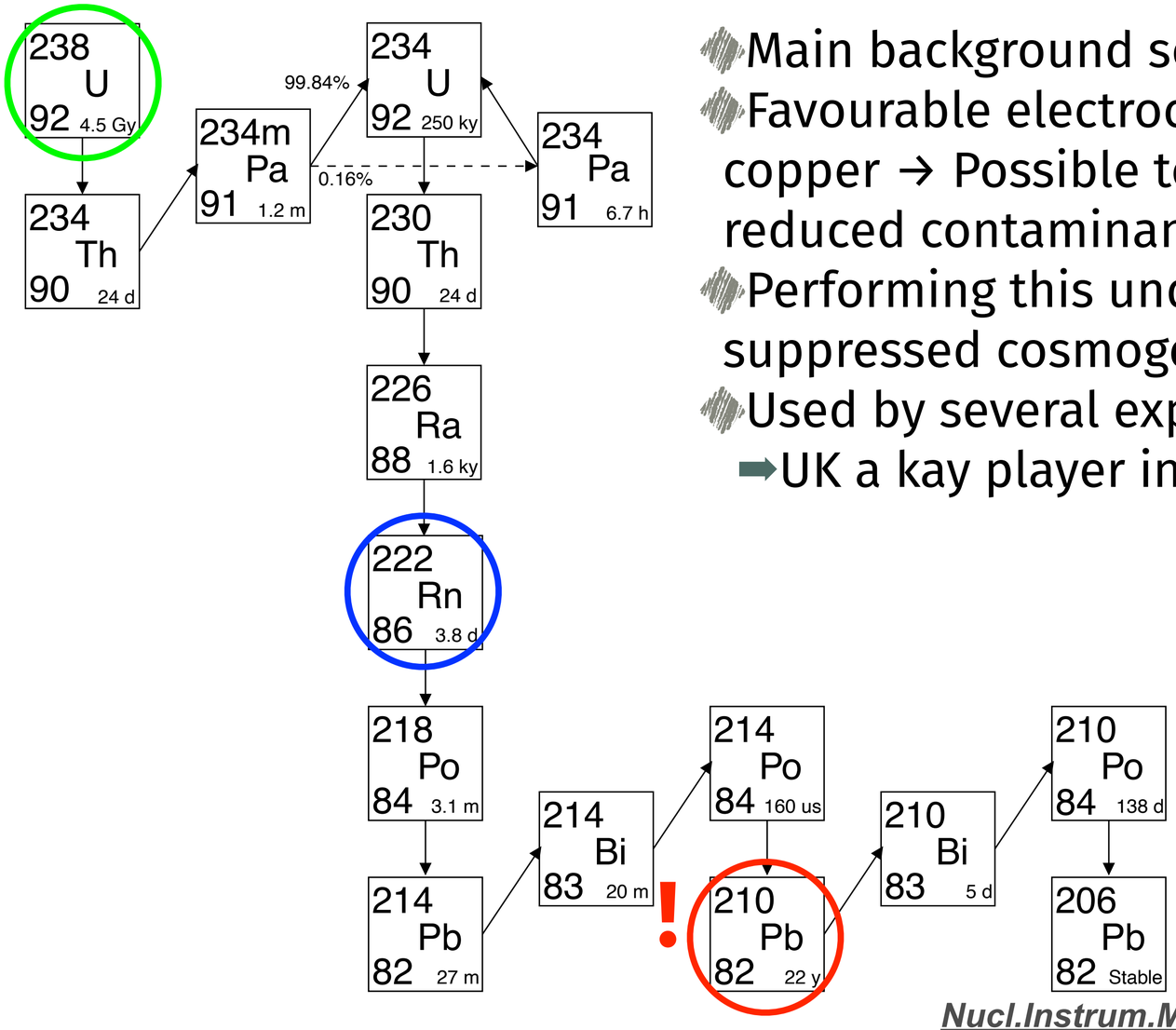


- Main background source Cu detector
- Favourable electrochemical properties of copper → Possible to produce copper with reduced contaminants (e.g. U, Th, K, etc.)
- Performing this underground → suppressed cosmogenic activation
- Used by several experiments, e.g. NEWS-G
  - ➡UK a kay player in this

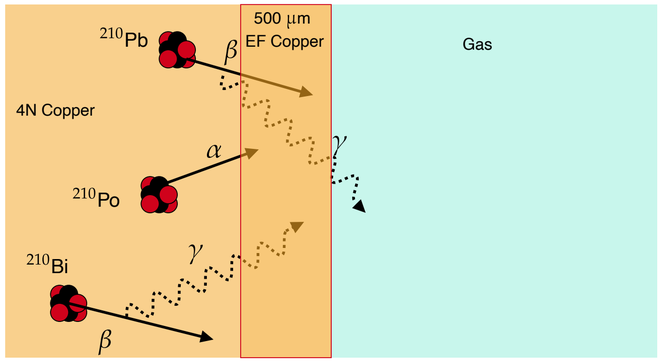


Nucl.Instrum.Meth.A 988 (2021) 164844

Ultra-Pure Cu Electroforming



- Main background source Cu detector
- Favourable electrochemical properties of copper → Possible to produce copper with reduced contaminants (e.g. U, Th, K, etc.)
- Performing this underground → suppressed cosmogenic activation
- Used by several experiments, e.g. NEWS-G
  - ➡UK a kay player in this

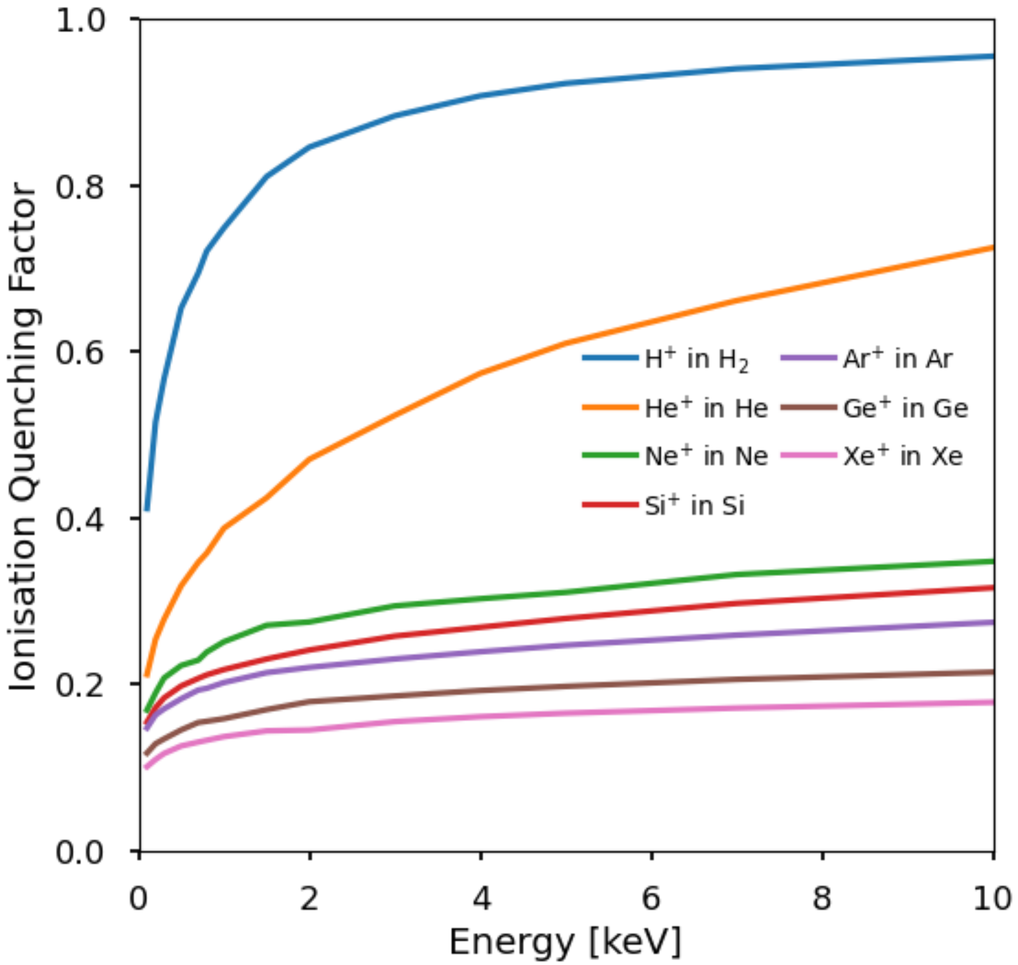


ICP-MS Assay

Sample	Weight [g]	^{232}Th [μBq kg^{-1}]	^{238}U [μBq kg^{-1}]
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

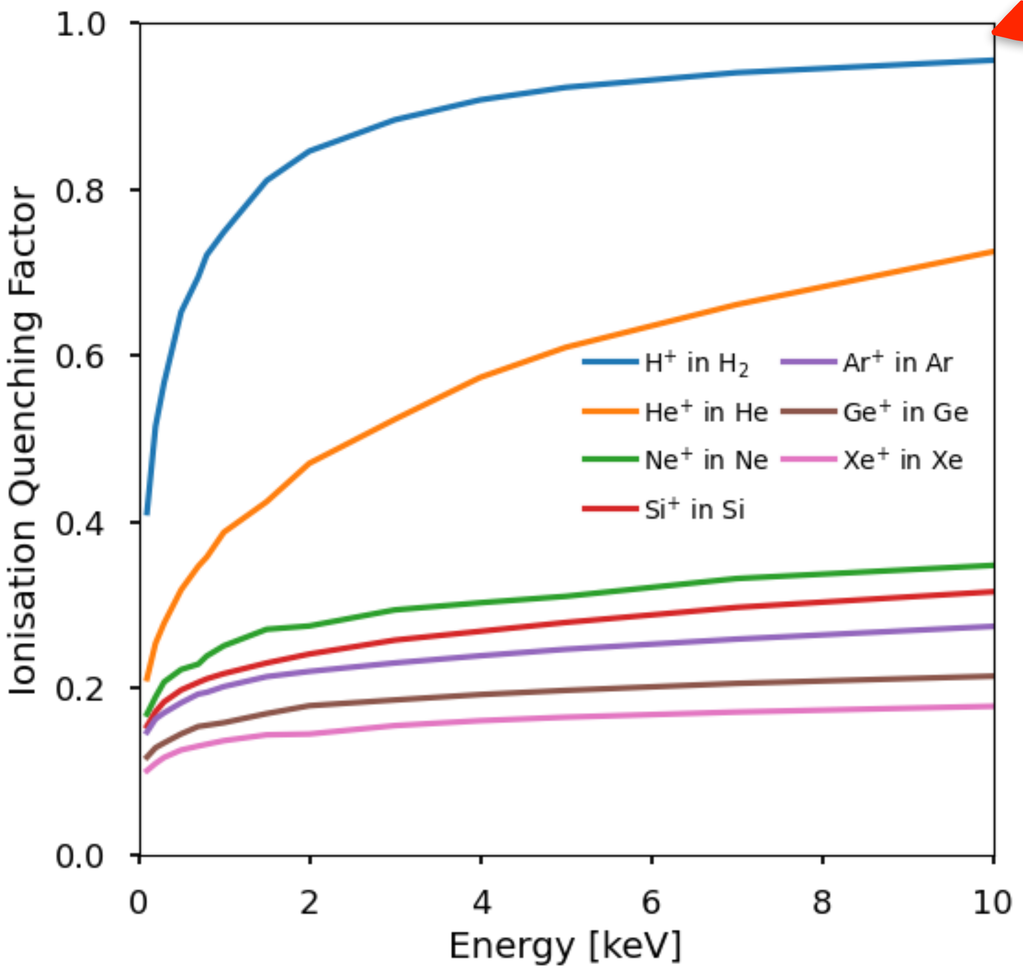
Nucl.Instrum.Meth.A 988 (2021) 164844

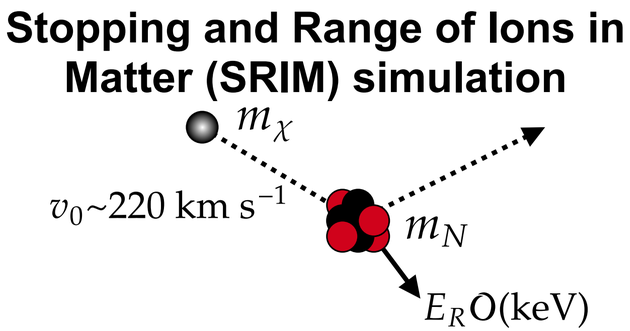
Ionisation Quenching Factor



- **Kinematic matching**: **low-mass targets** are **favourable for light-DM** detection by nuclear recoils
- **Light targets** have **favourable quenching factors**

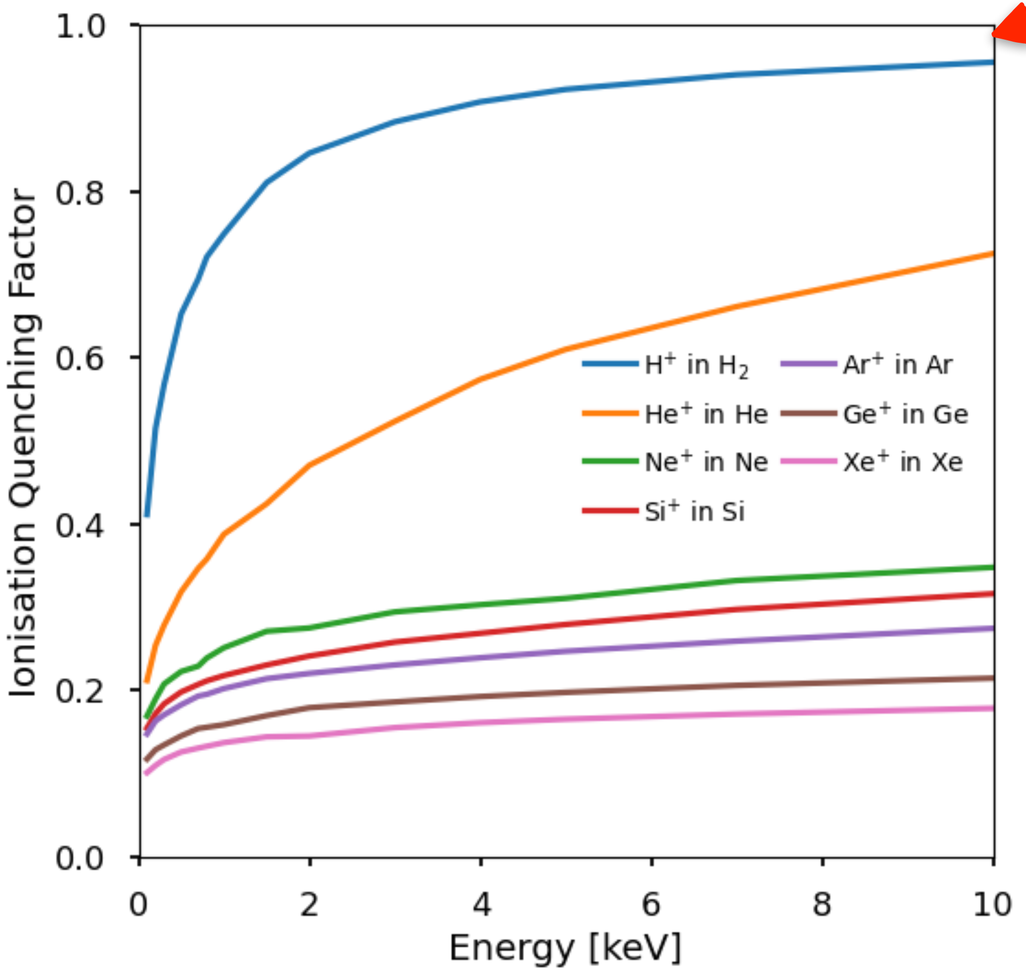
Ionisation Quenching Factor

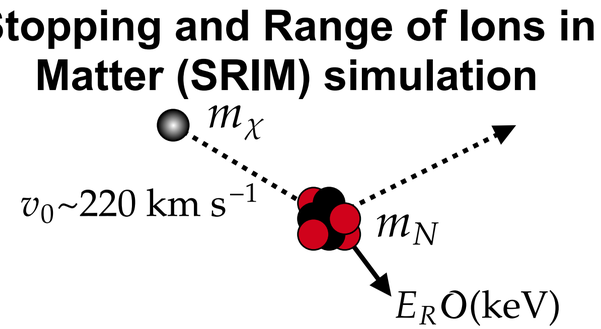




- **Kinematic matching**: **low-mass targets** are **favourable for light-DM** detection by nuclear recoils
- **Light targets** have **favourable quenching factors**

Ionisation Quenching Factor

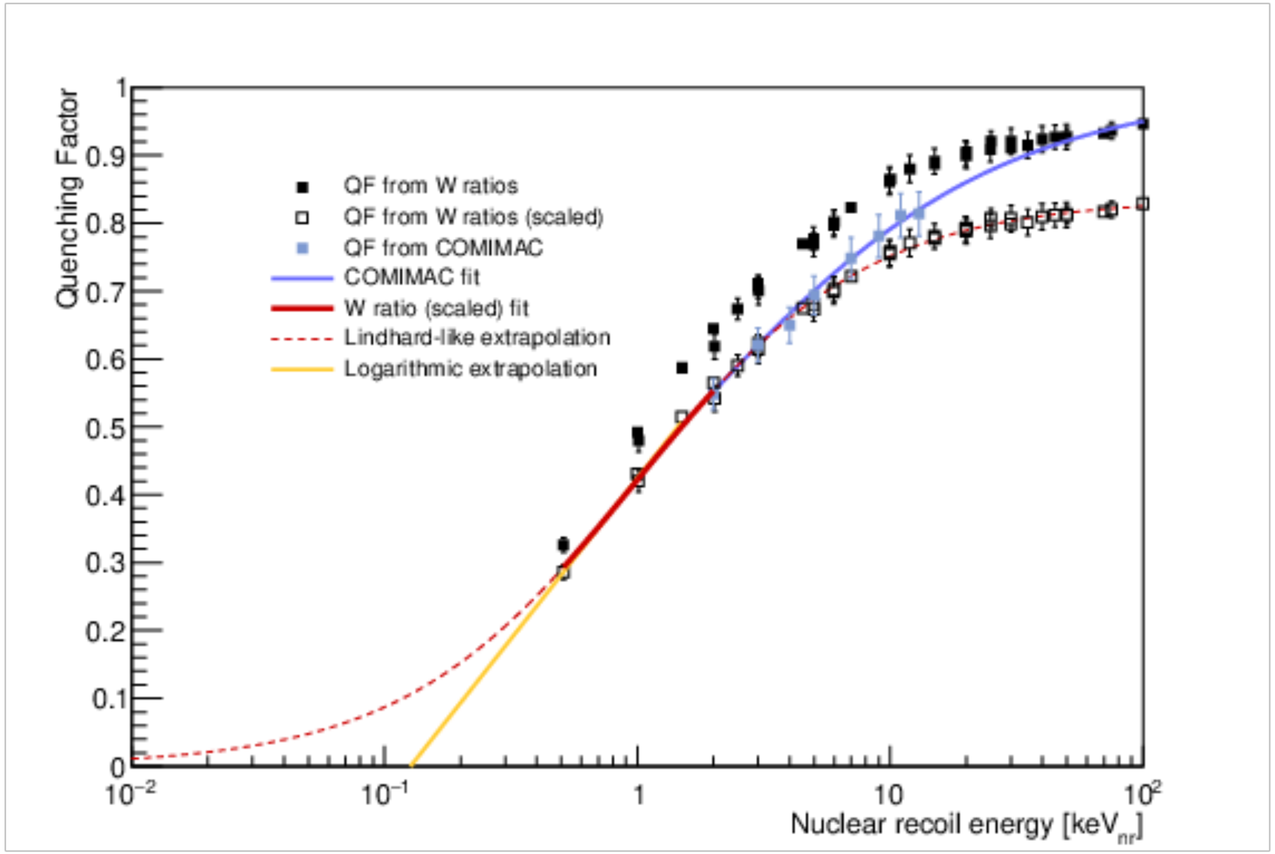


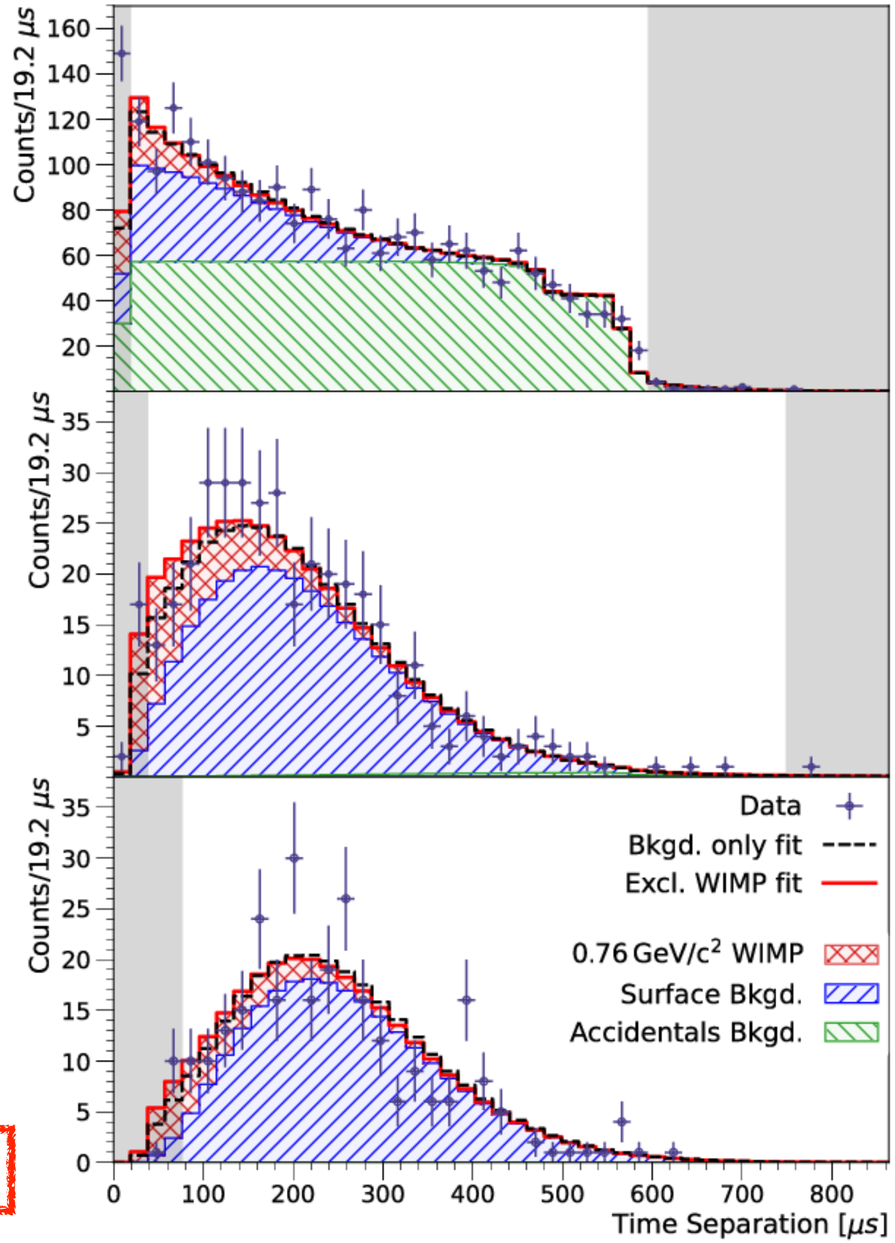


- **2 measurement approaches** in NEWS-G
  - Neutron scattering at TUNL — *Phys.Rev.D 105 (2022) 5, 052004*
  - Electron/Ion beam, COMIMAC, Grenoble — *Eur.Phys.J.C 82 (2022) 12, 1114*
- **Innovative approach** using literature measurements — *Astropart.Phys. 141 (2022) 102707*

- **Kinematic matching**: **low-mass targets** are **favourable for light-DM** detection by nuclear recoils
- **Light targets** have **favourable quenching factors**

NEWS-G Results





https://arxiv.org/abs/2407.12769