

Searching for Light-Dark Matter with NEWS-G

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IOP APP Early Career Prize 2023 Talk

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The Dark Matter Puzzle

One of the greatest mysteries of modern physics:

'What makes up 84% of matter?'

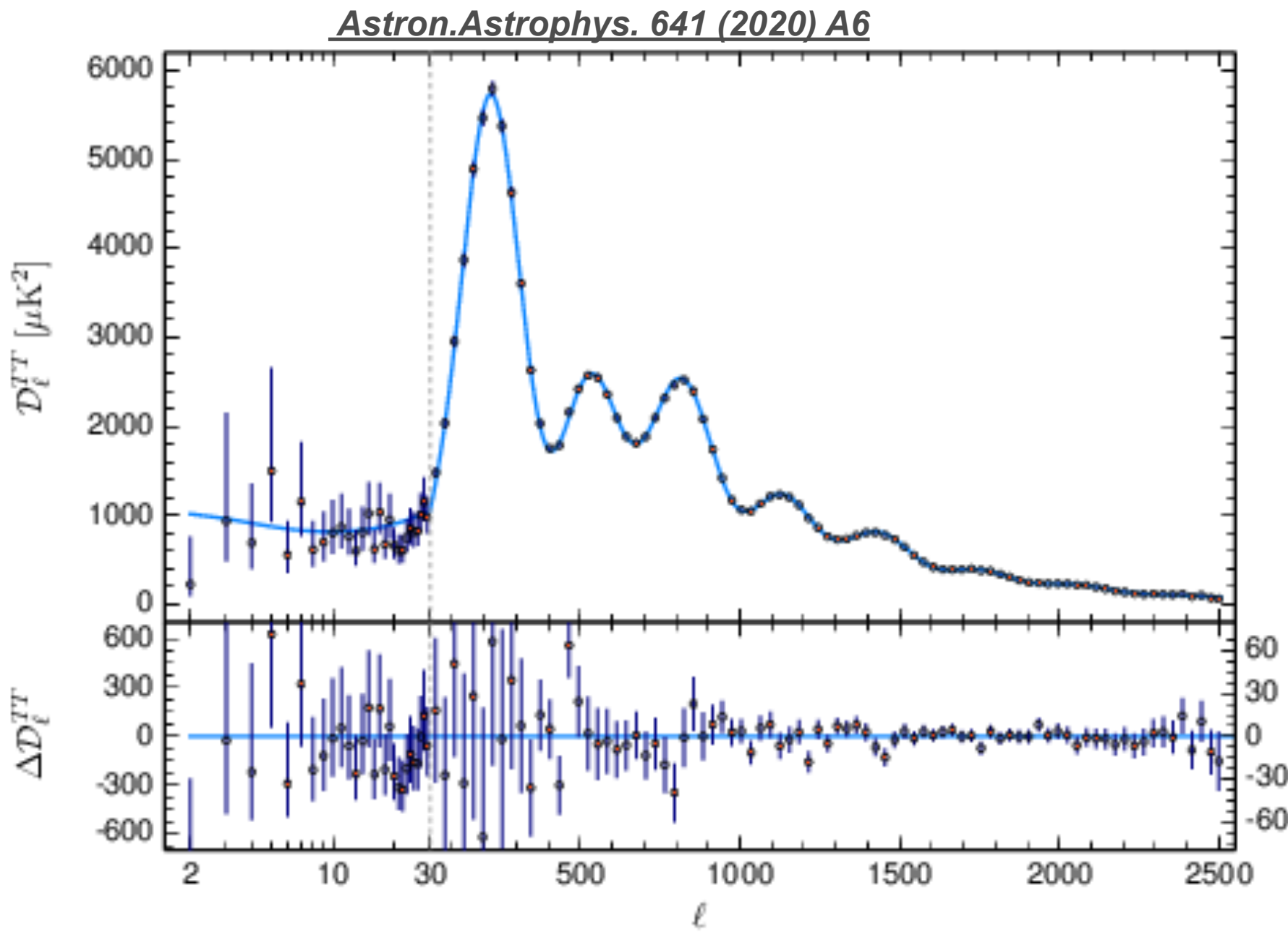
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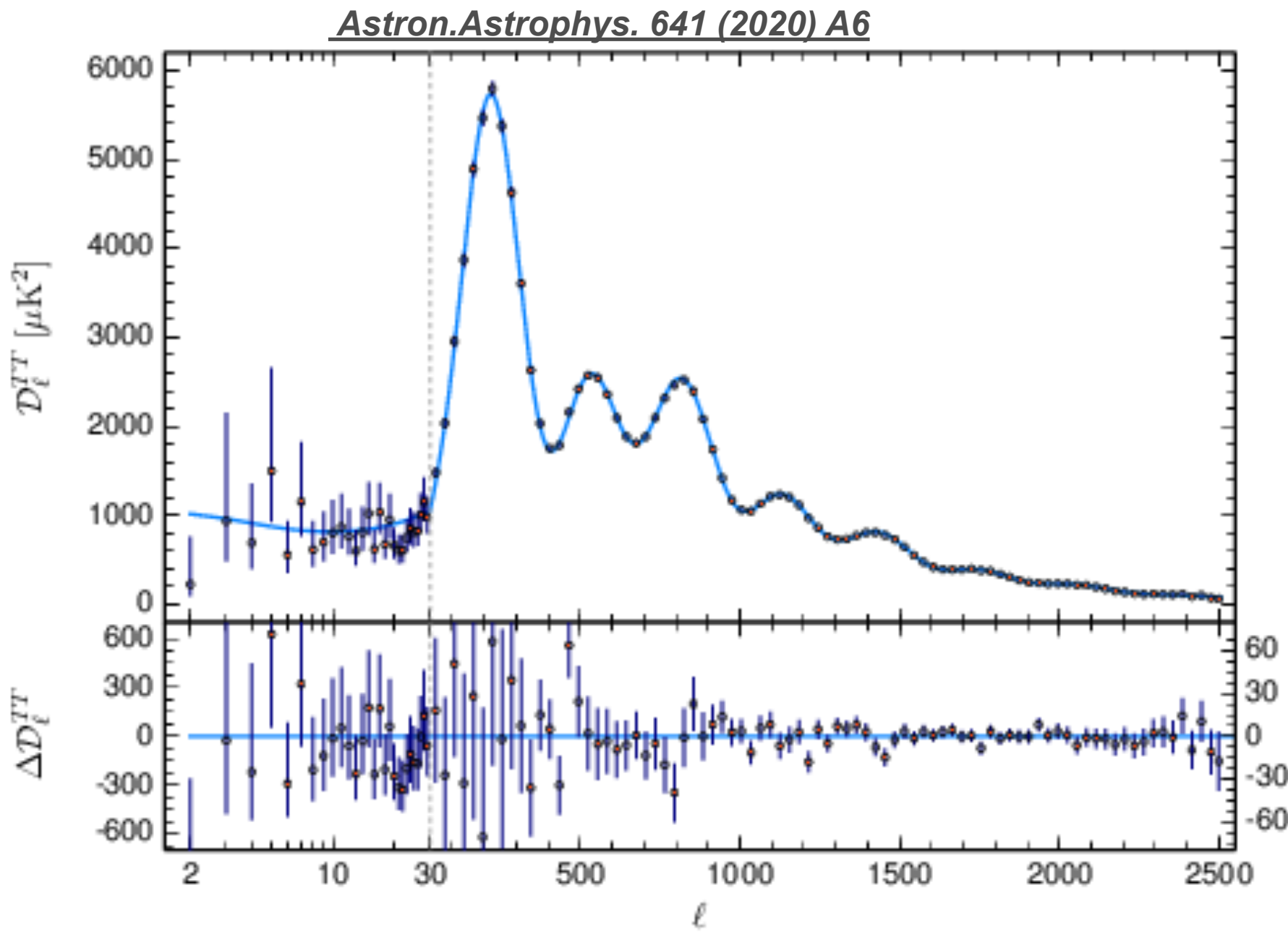
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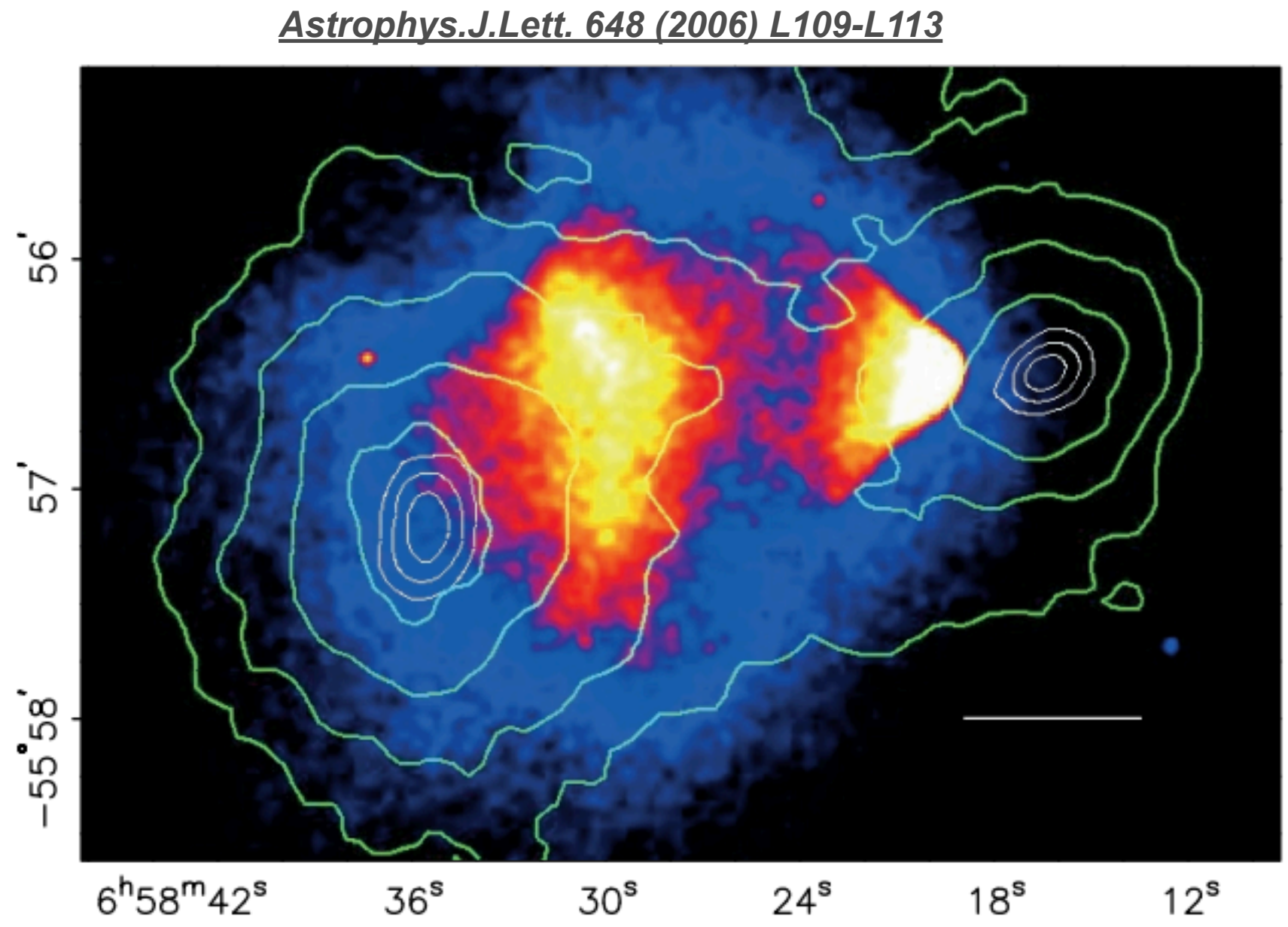
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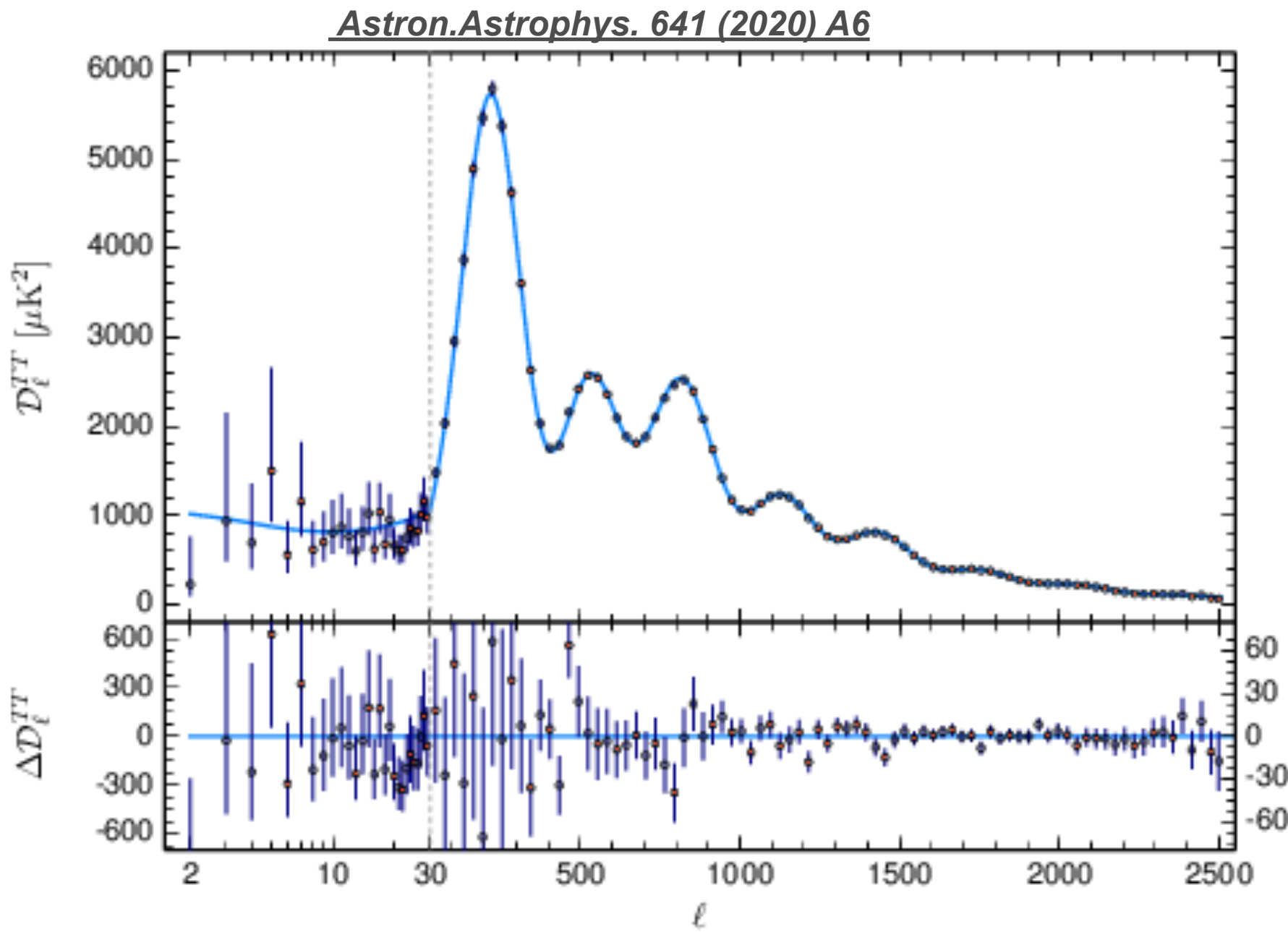
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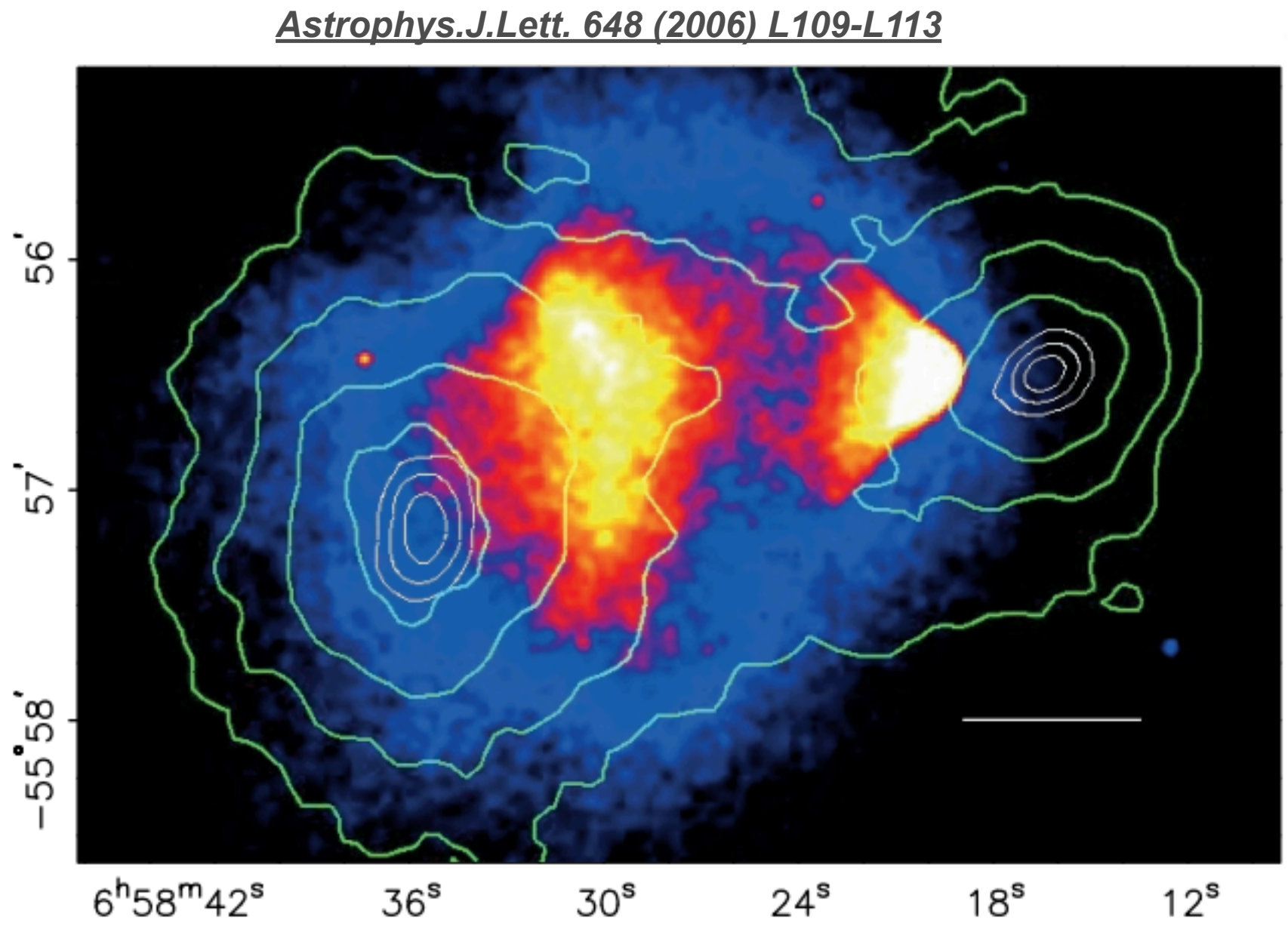
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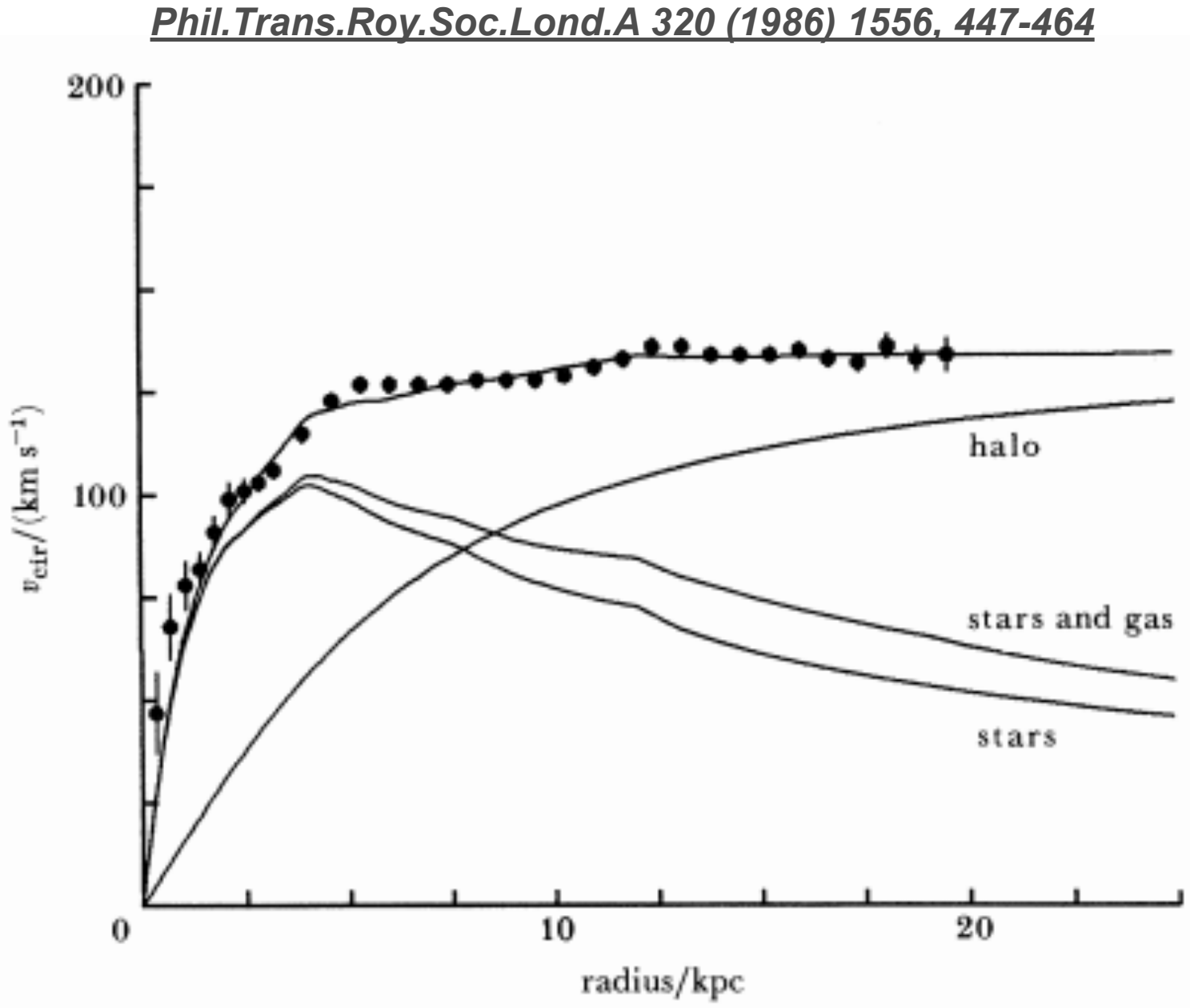
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Galactic rotation curves

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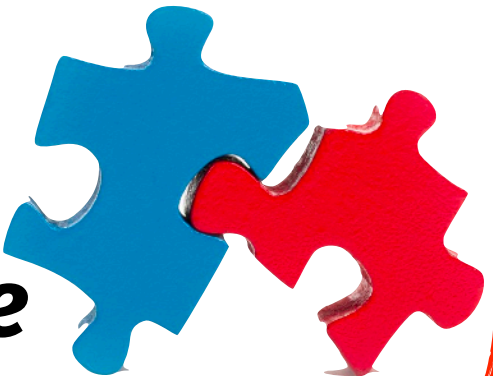
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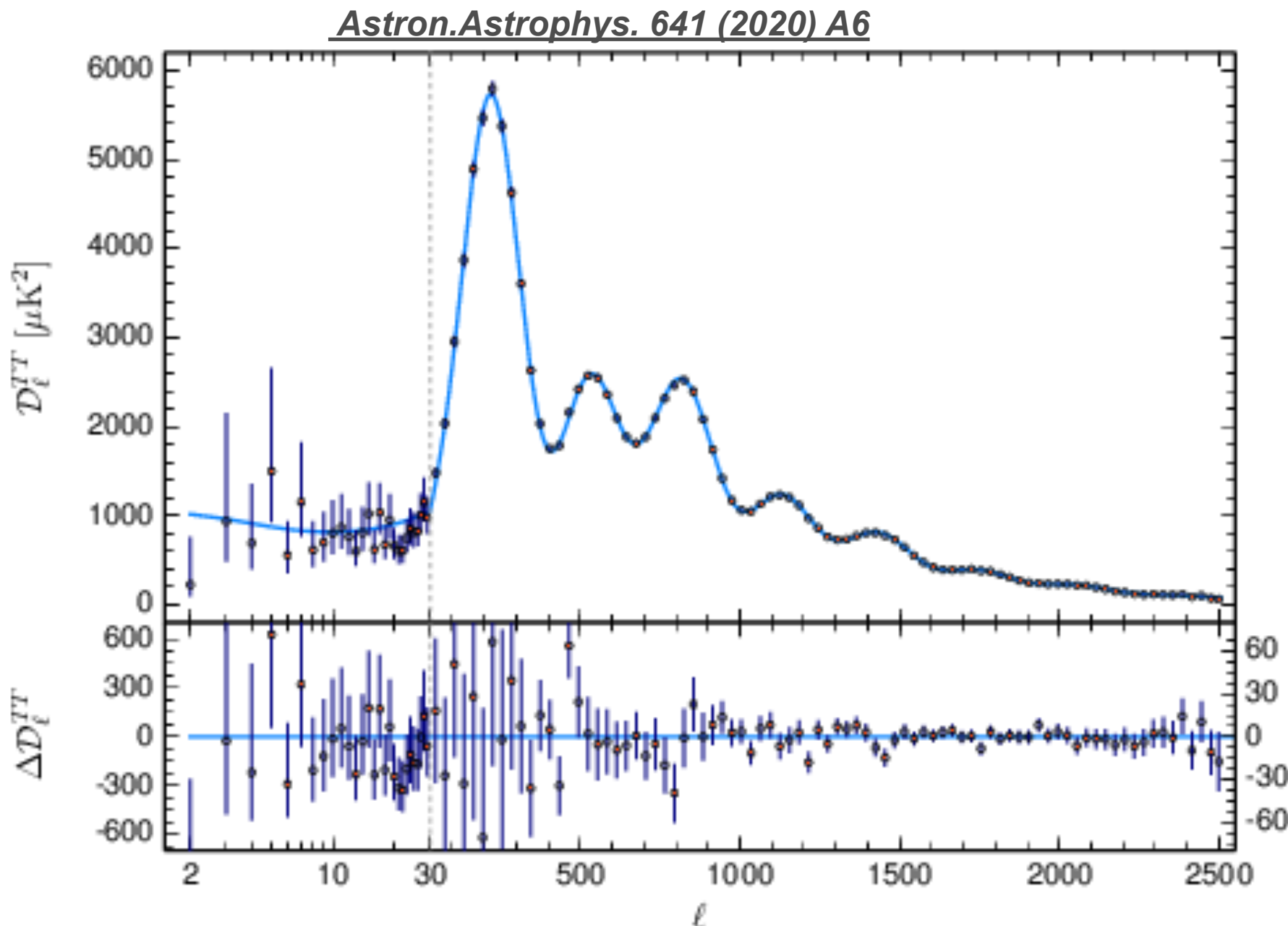
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DM properties:

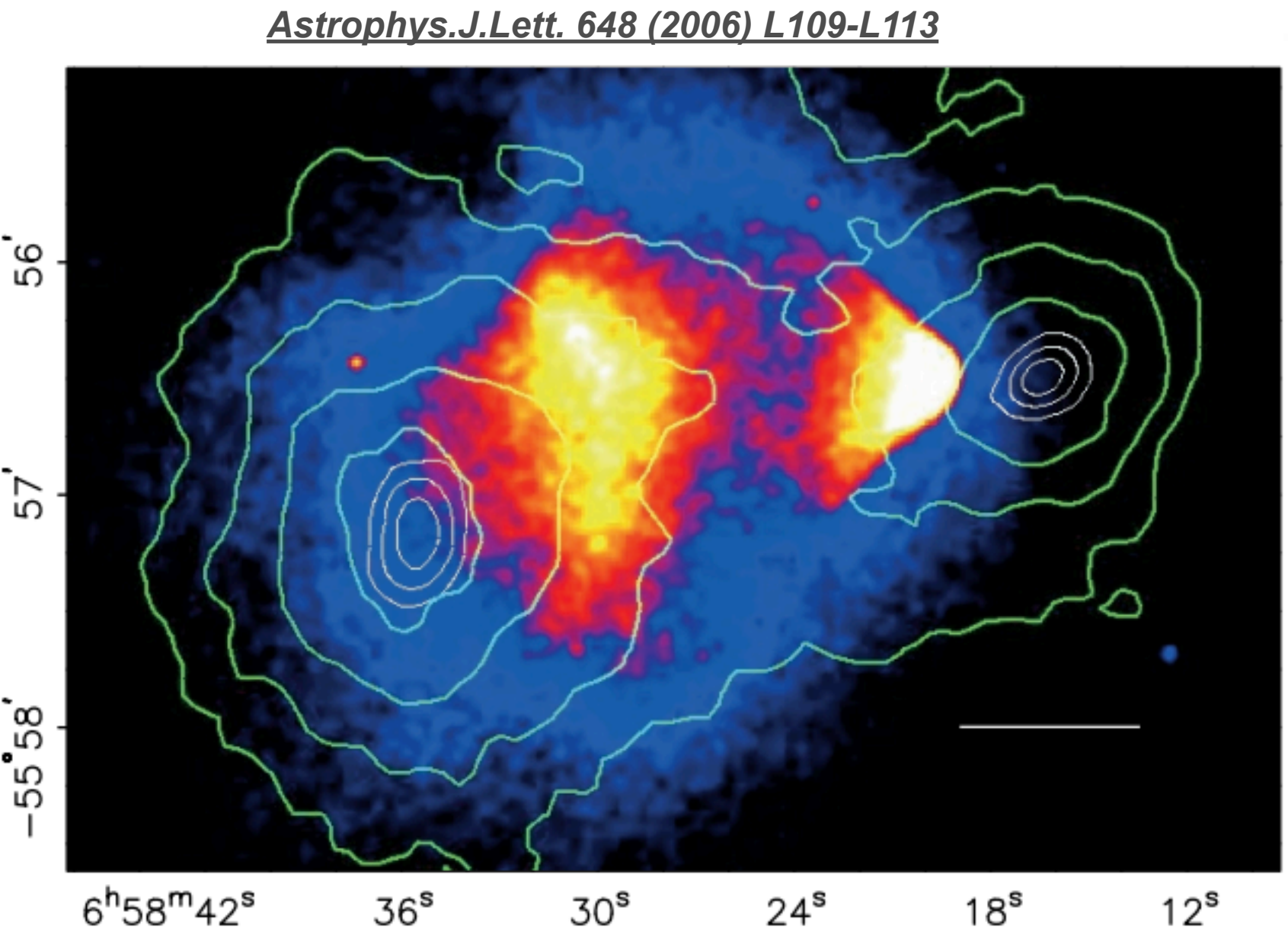
- 'Weakly' interacting
- Non-baryonic
- Electrically neutral
- Non-relativistic
- Long-lived



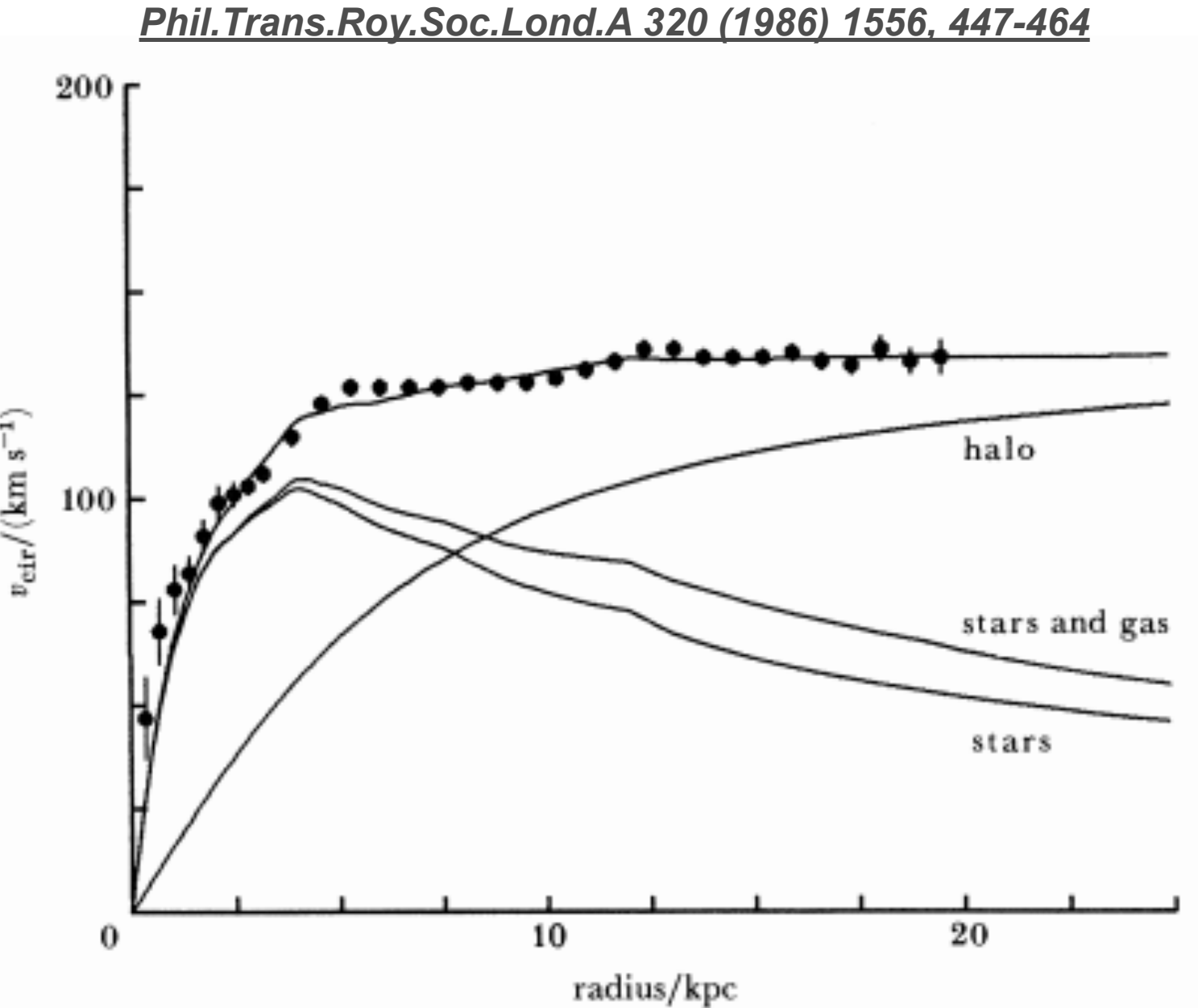
No known particle solves the puzzle!



Cosmic Microwave Background



Gravitational lensing

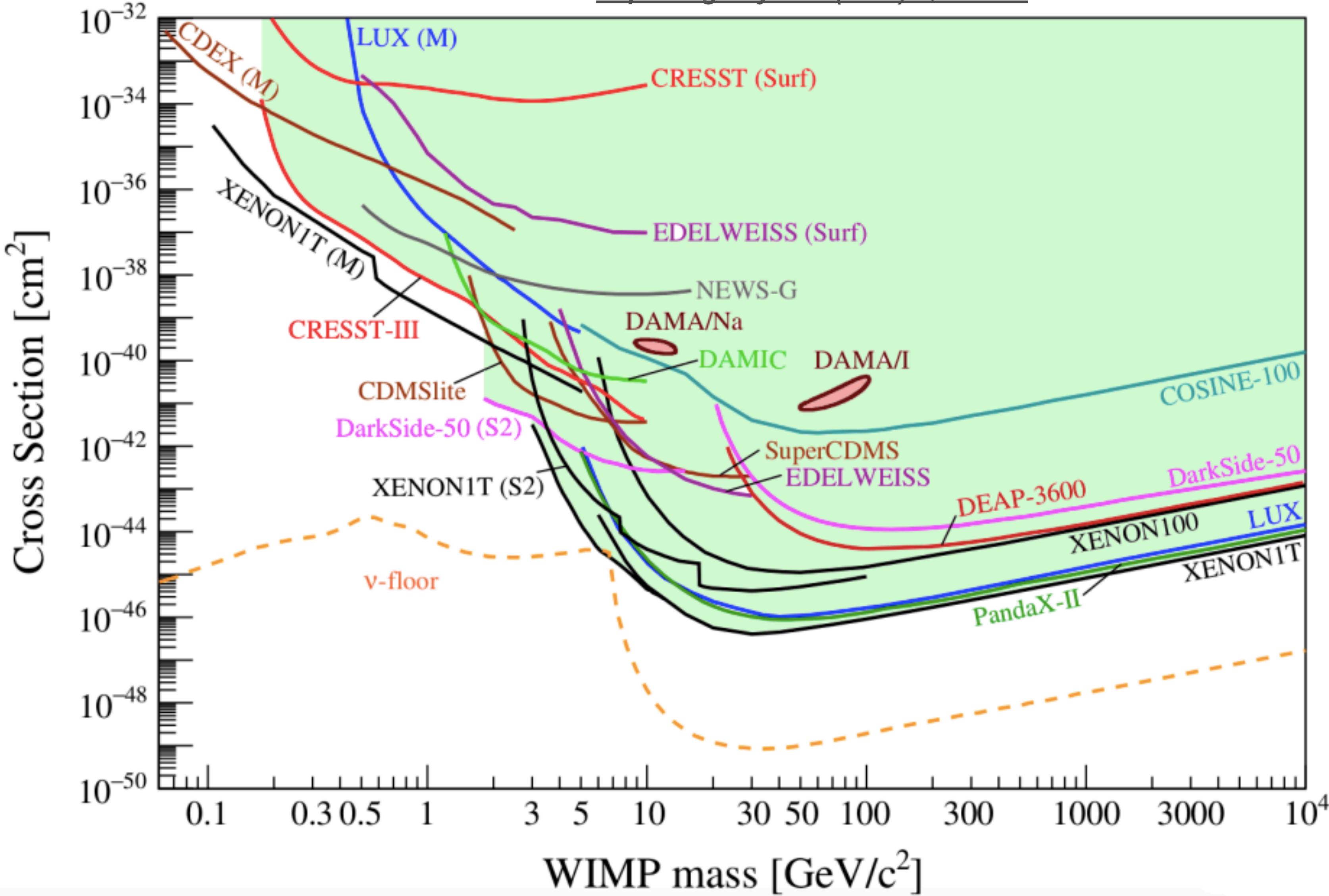
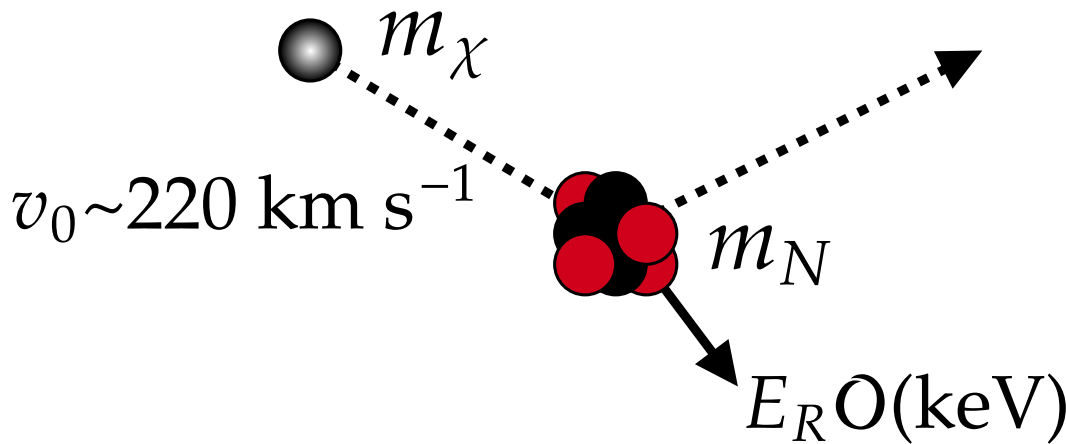


Galactic rotation curves

Landscape of Direct DM Searches

[See A Cottle's Talk \(next\), 11:40 Tuesday](#)

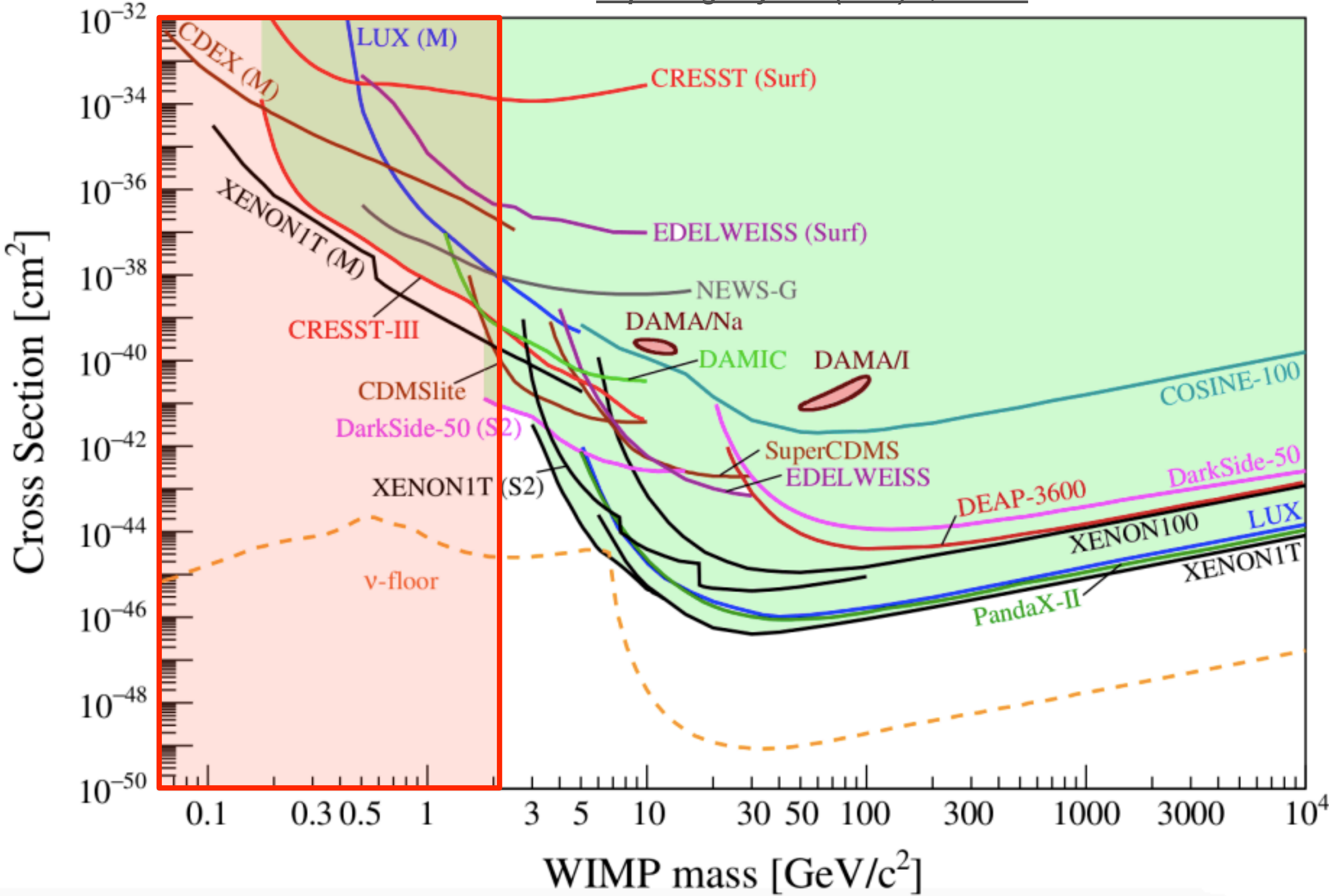
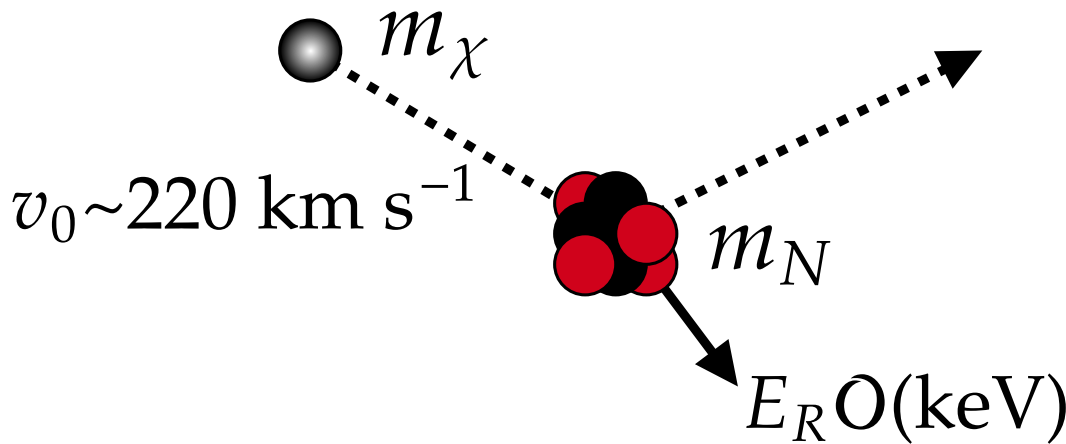
Rept.Prog.Phys. 85 (2022) 5, 056201



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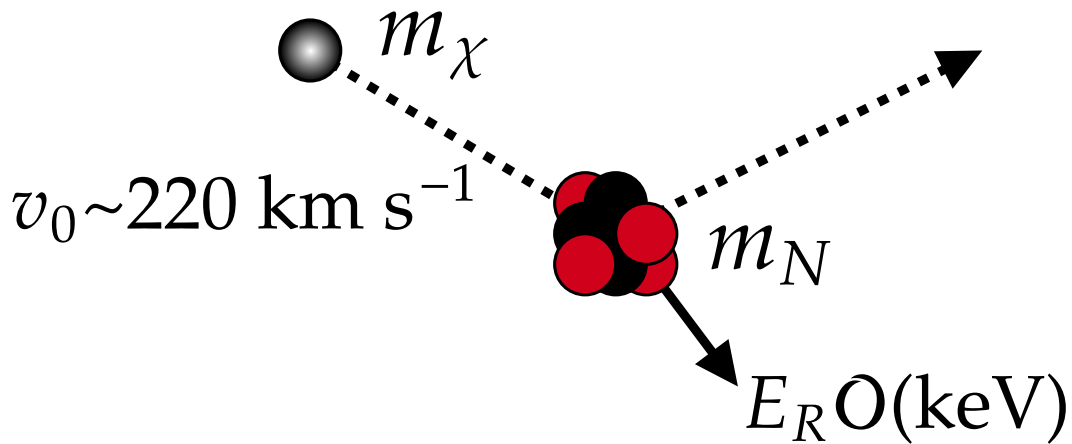
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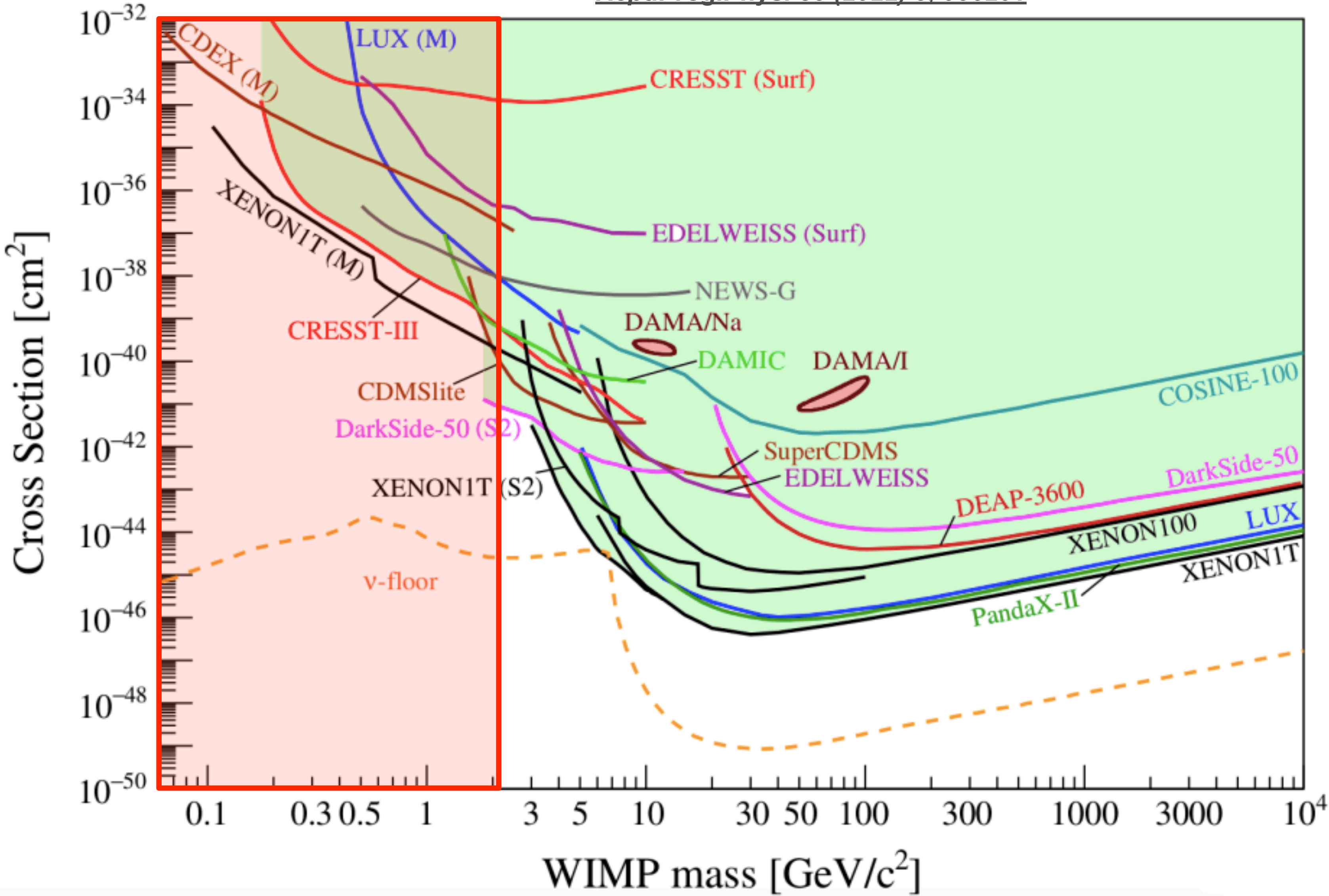
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Light DM region has **attracted theoretical** interest

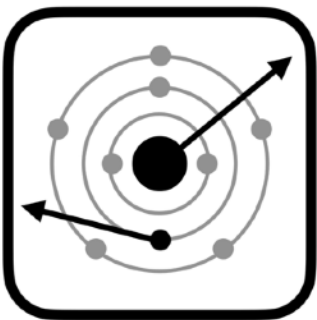
Exploring **light DM** with nuclear recoils requires:

- ➔ Low energy threshold
- ➔ Low-mass target nuclei
- ➔ Novel approaches



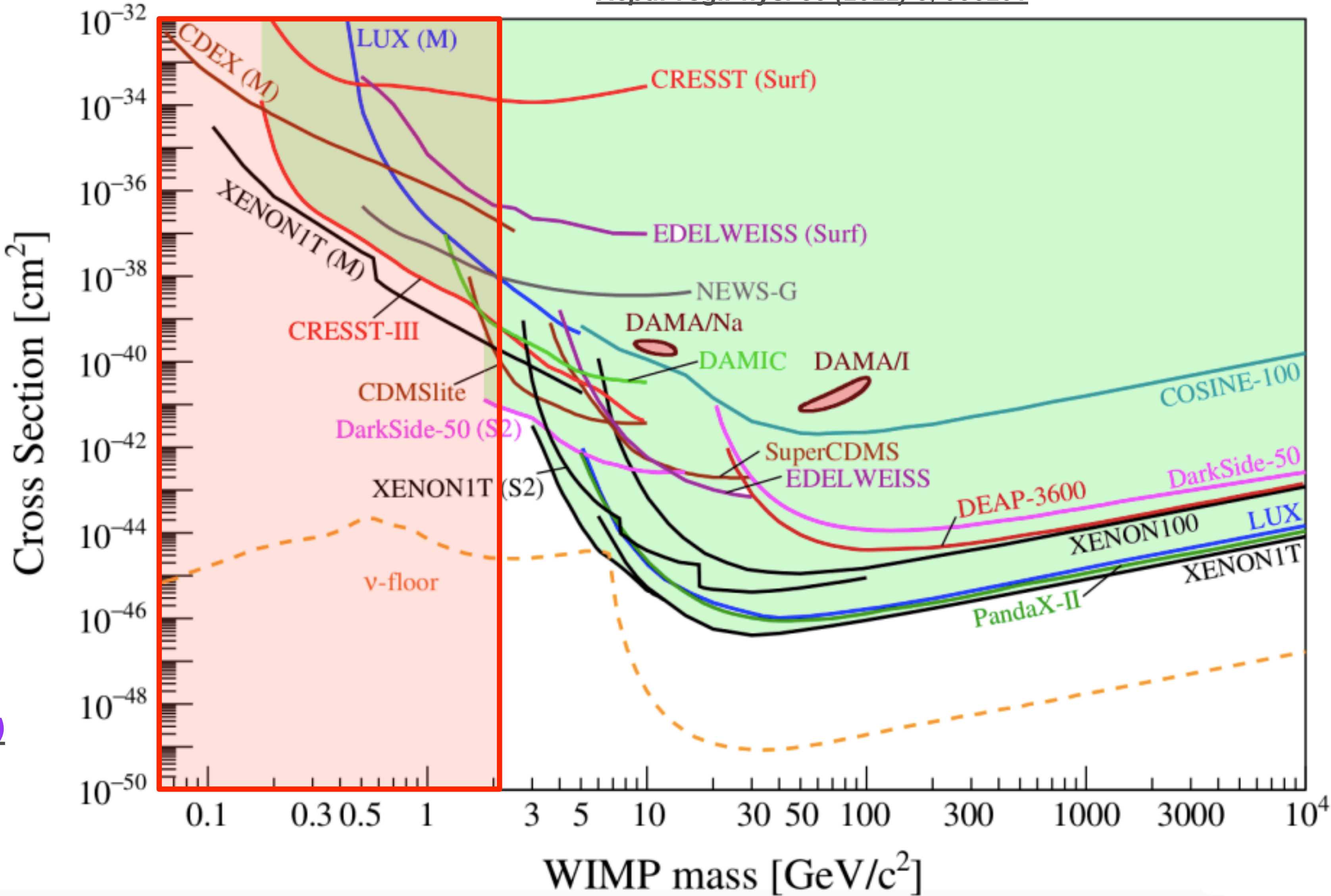
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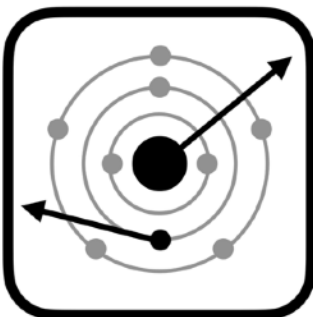
MIGDAL
Migdal In Galactic Dark mAtter expLoration

[More on MIGDAL: L Millins' Poster \(Tuesday\)](#)



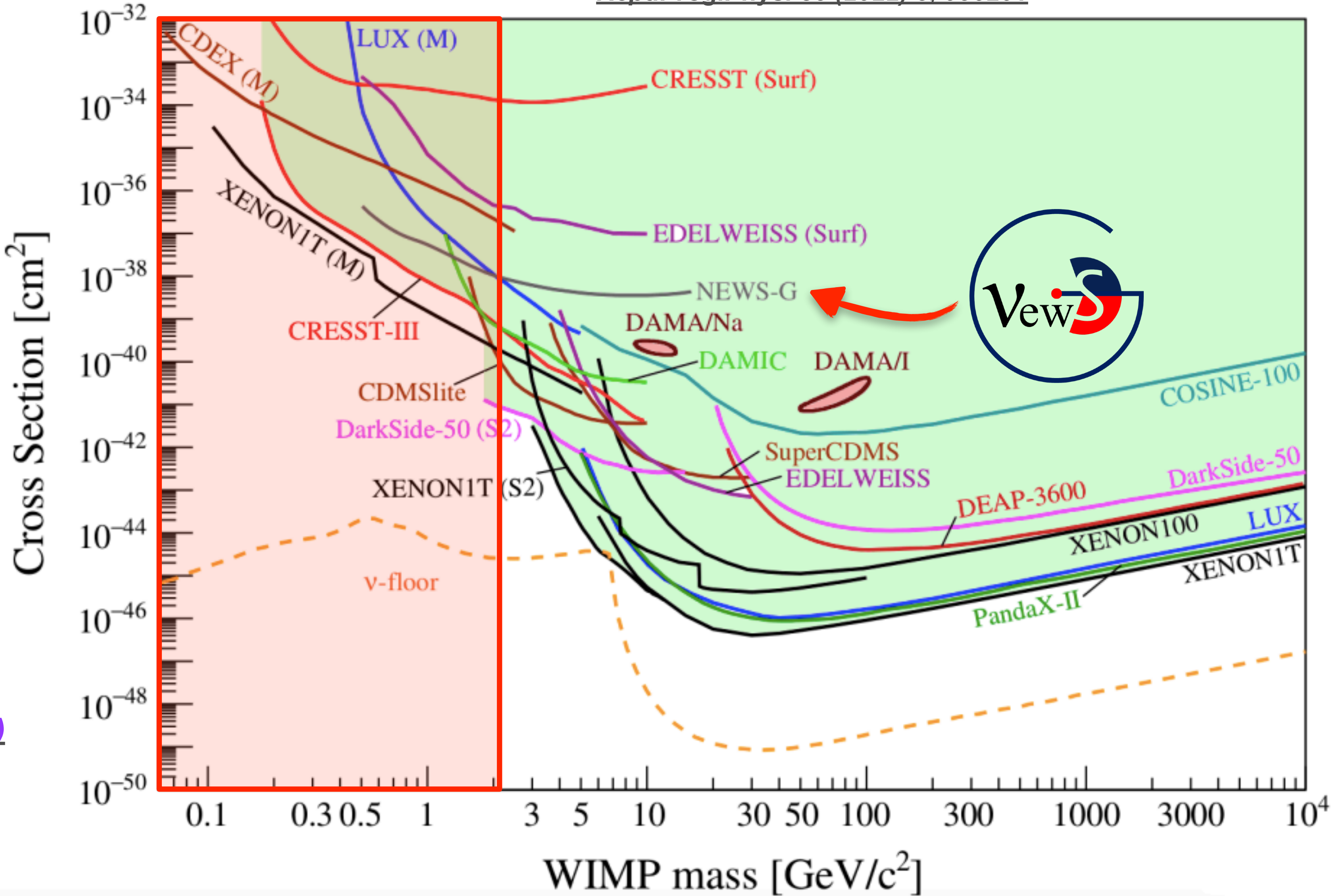
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NEWS-G

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



Boulby Underground Laboratory



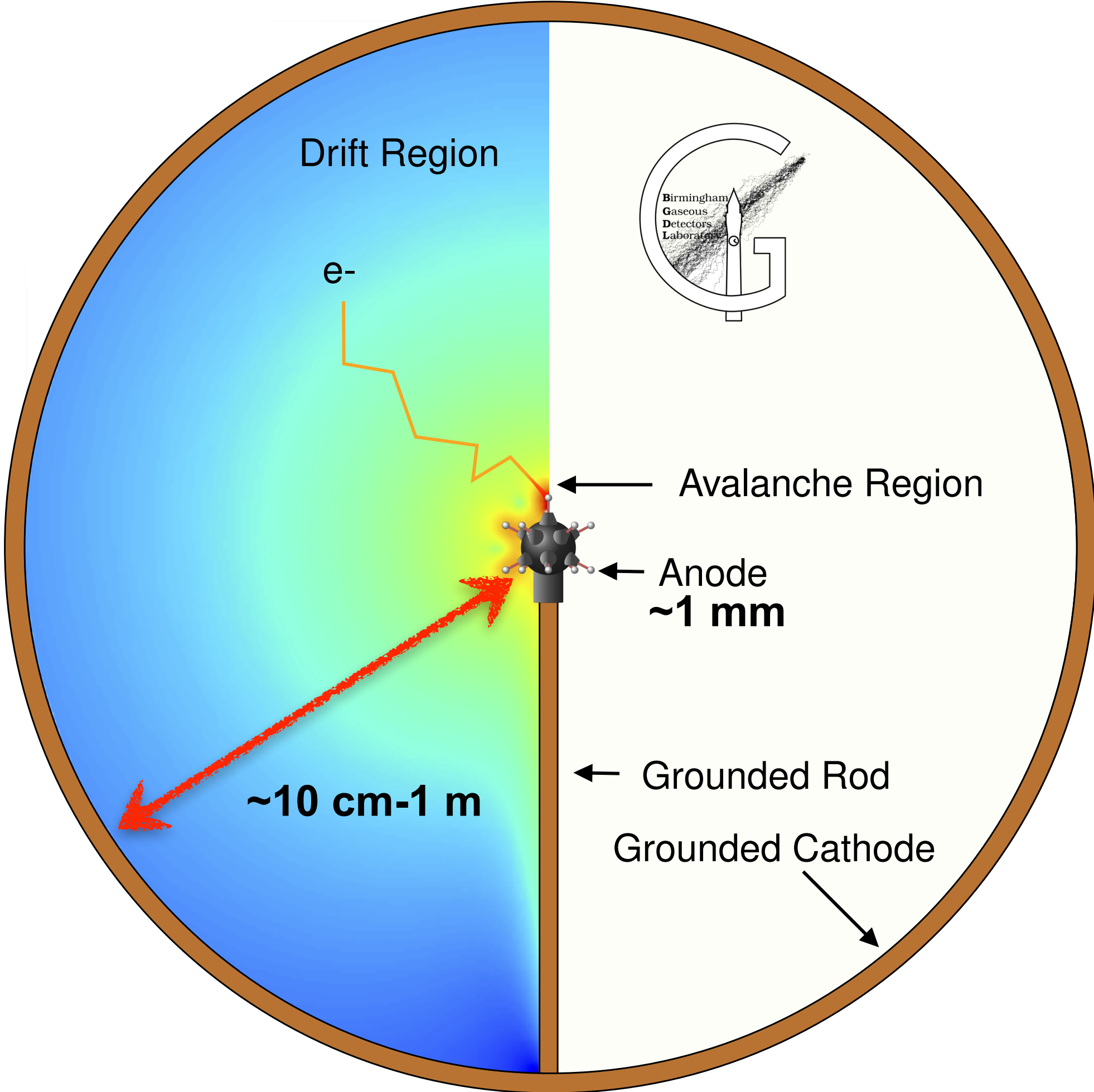
UNIVERSITY OF BIRMINGHAM



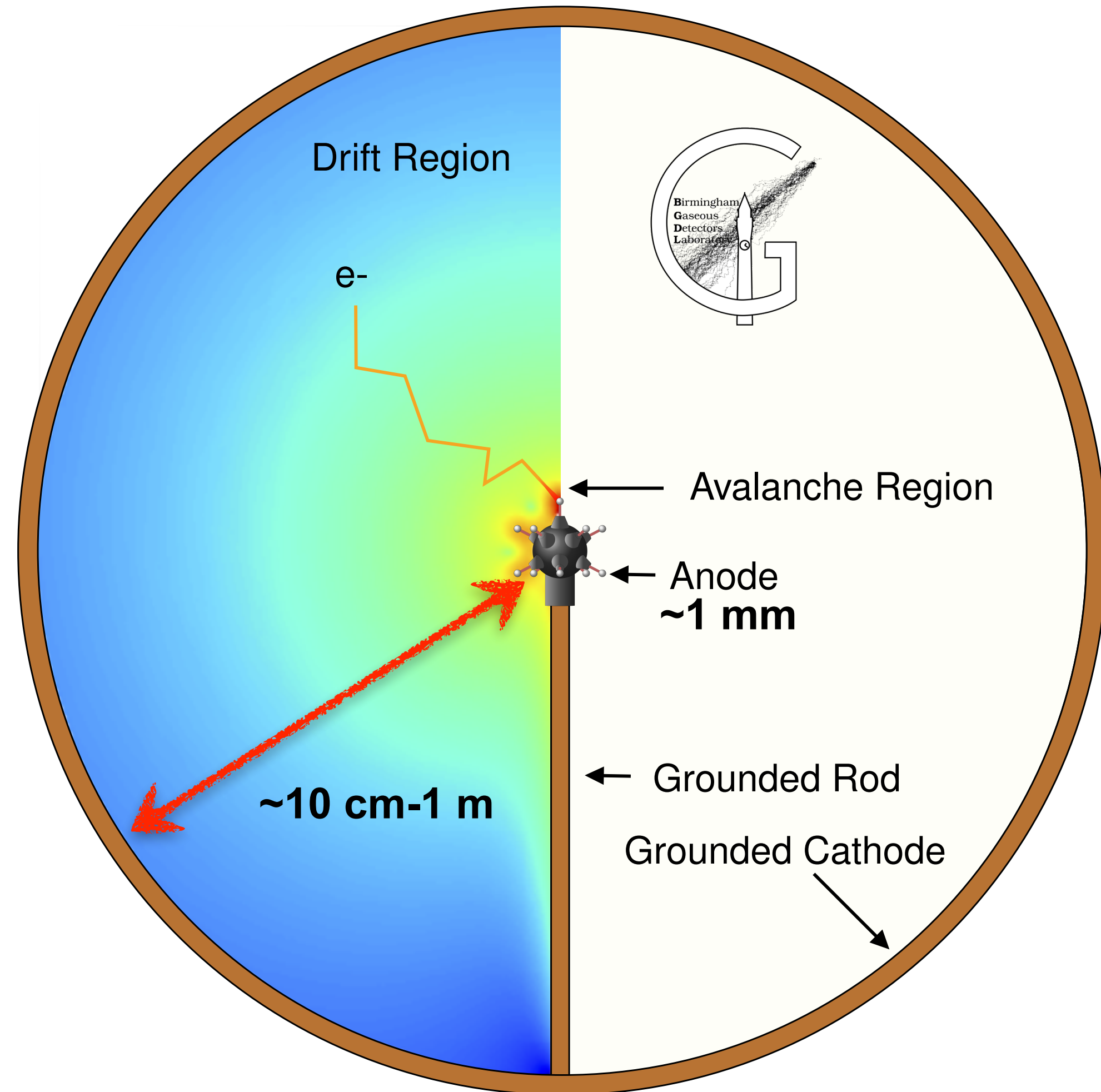
Spherical Proportional Counters

$$\vec{E} \approx \frac{V_1}{r^2} r_a \hat{r}$$

$$C \approx 4\pi\epsilon_0 r_a$$



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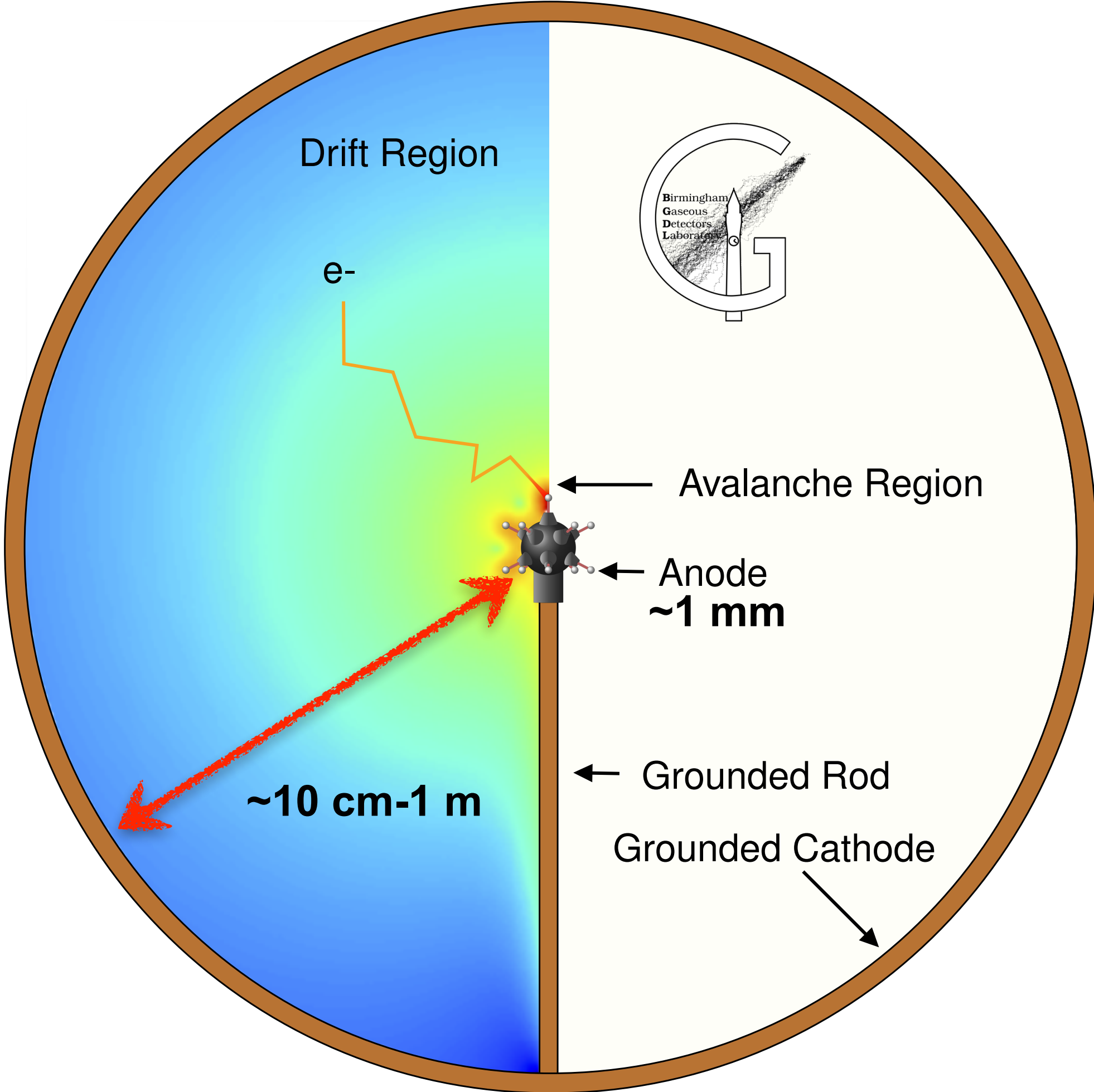
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Strengths in Direct DM Searches:

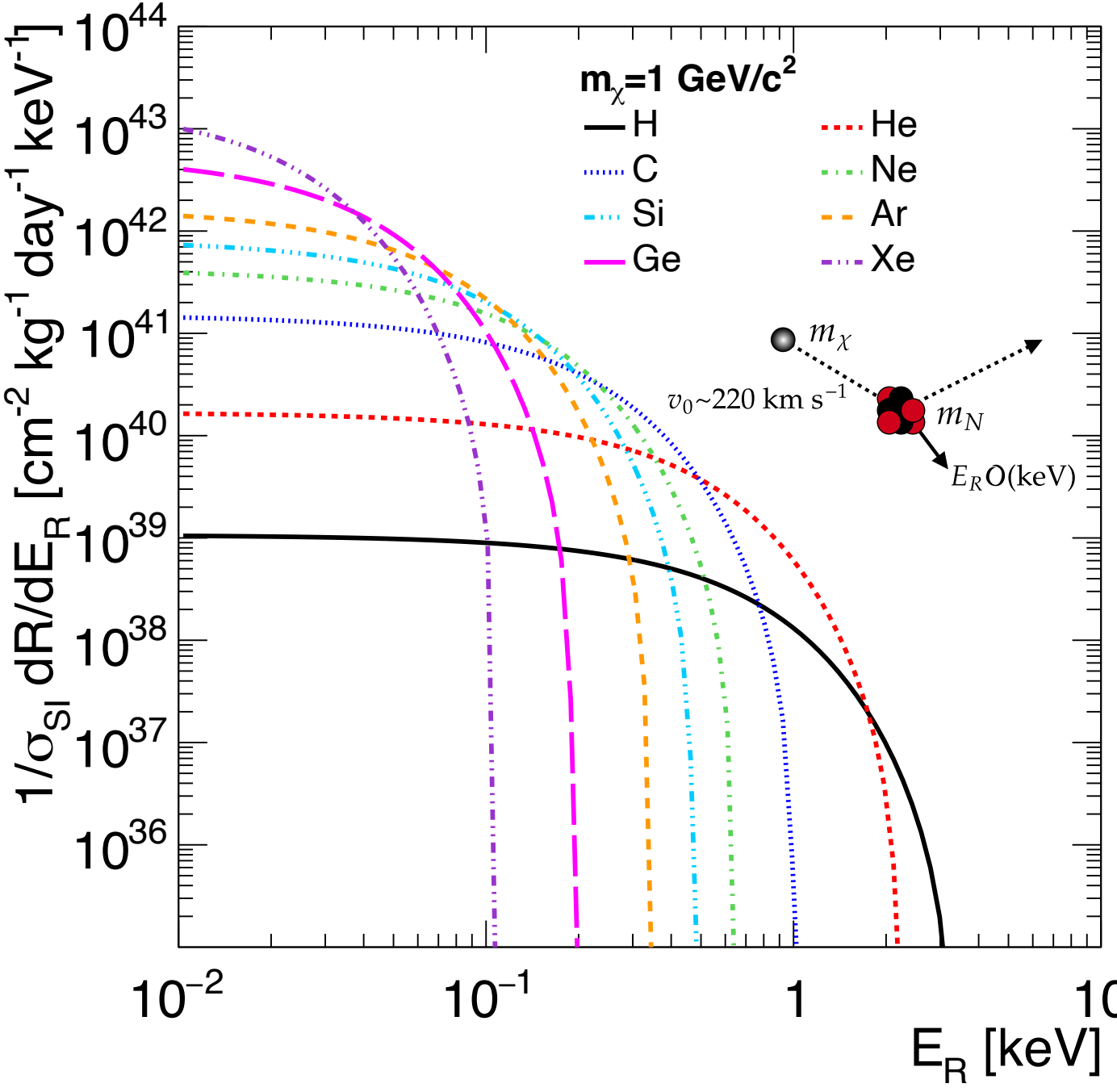
- ◆ **Choice of gas targets and pressures**
- ◆ **Low capacitance, single-electron detection**
- ◆ **Lowest surface area to volume ratio**
- ◆ **Fiducialisation (event localisation)**
- ◆ **Simple, few-channel read-out**
- ◆ **Radiopure construction**

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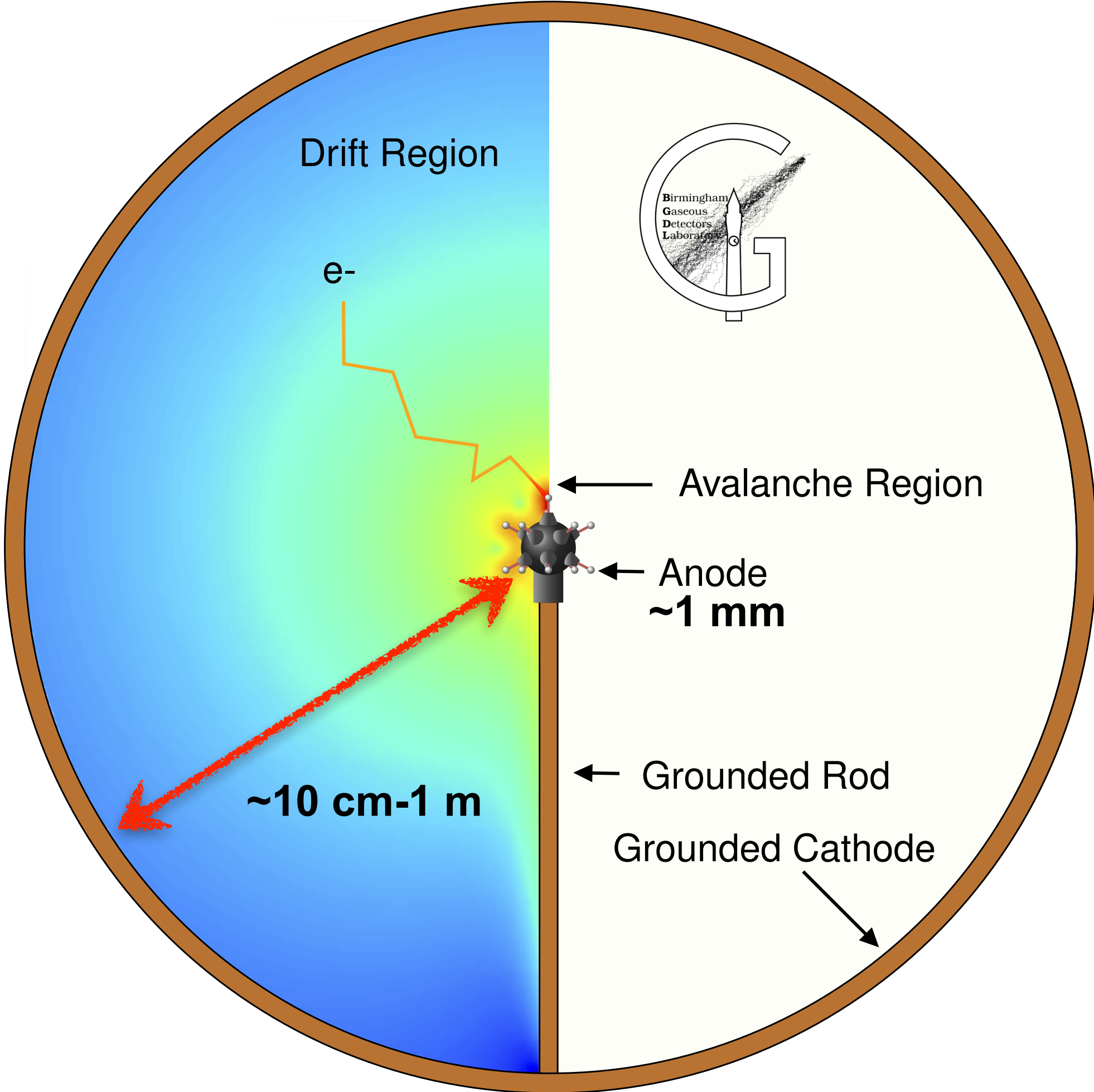
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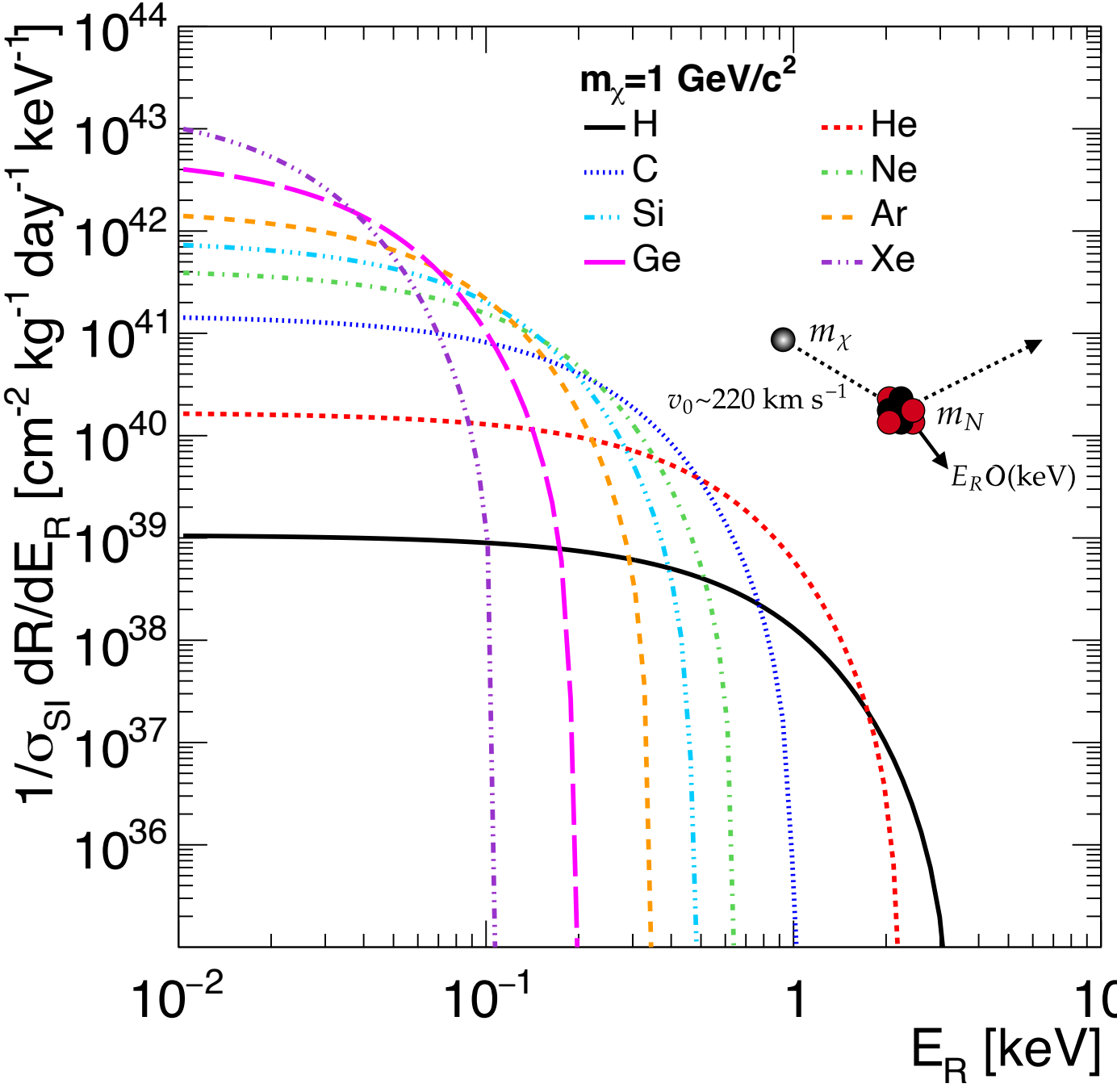
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Spherical Proportional Counters



NEWS-G S140 in SNOLAB

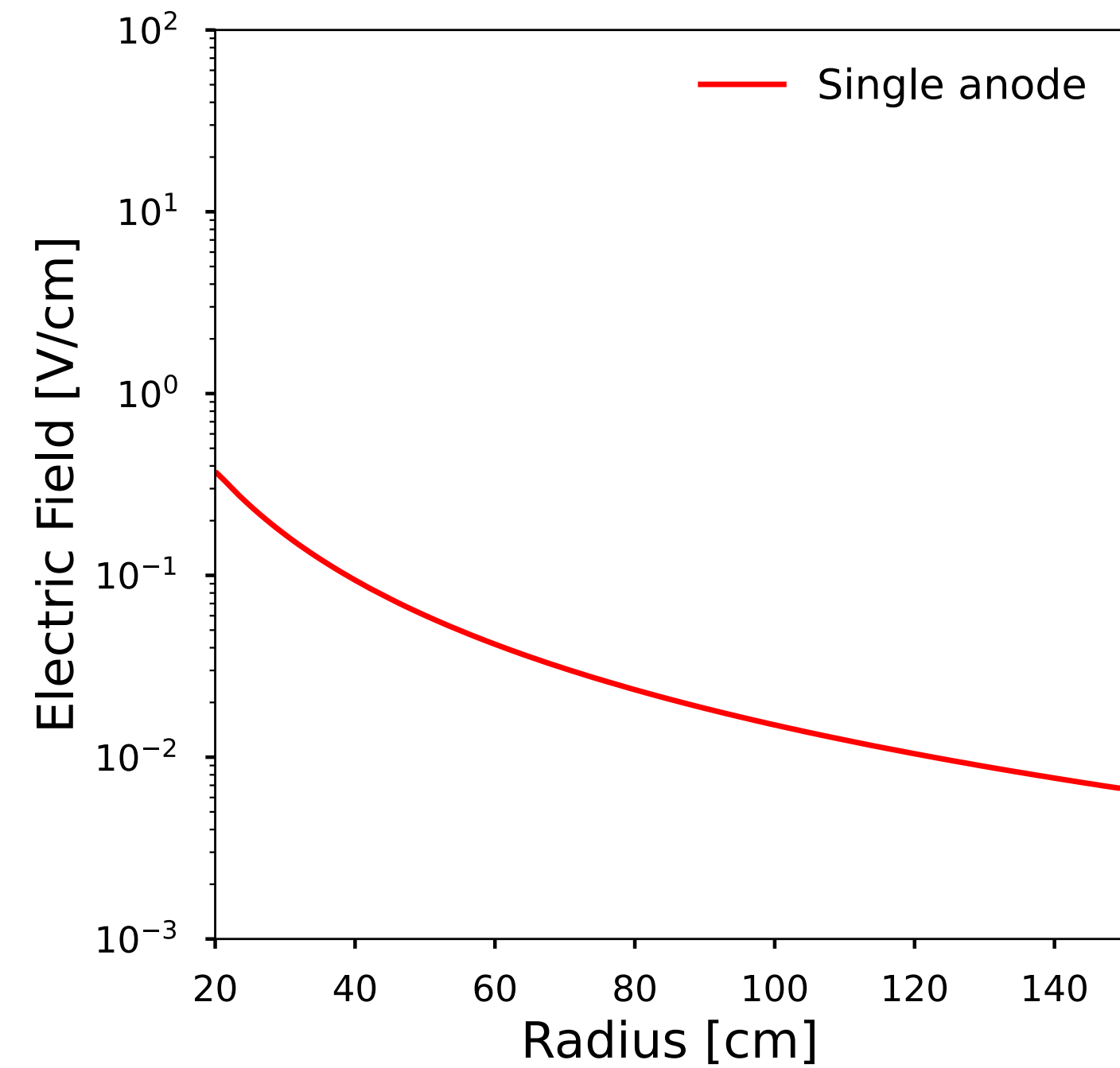


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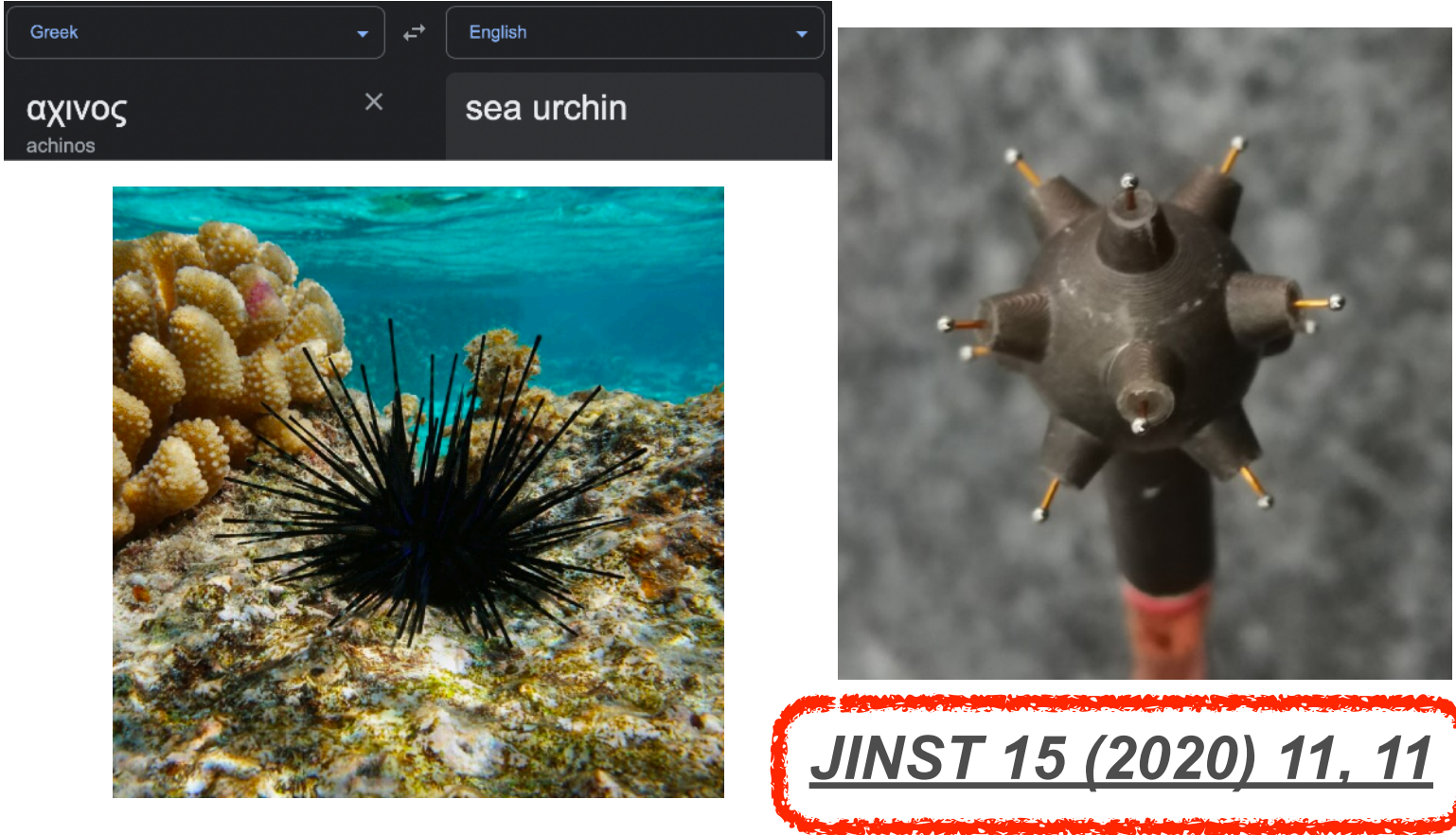
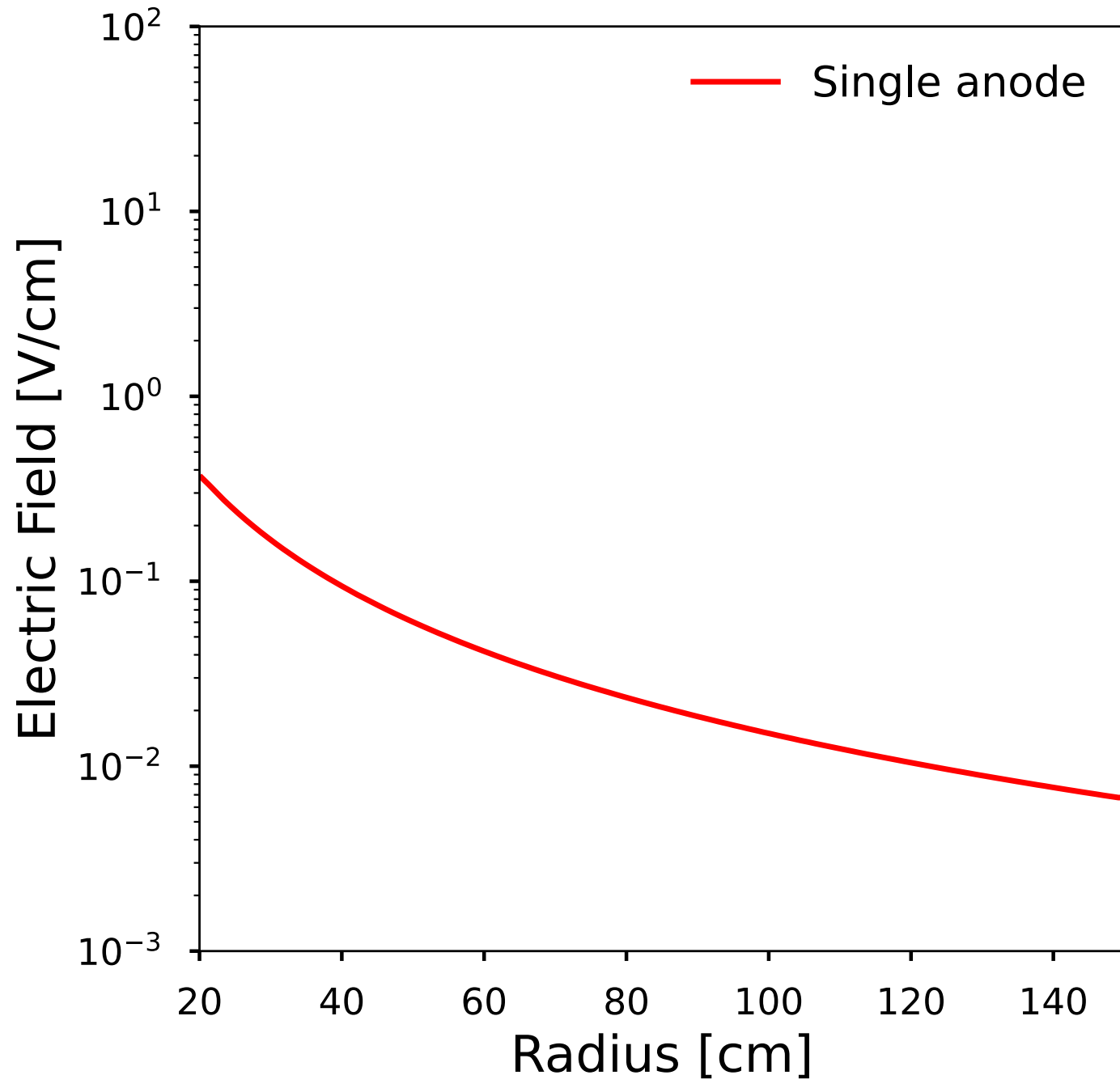
SPC Instrumentation

- ◆ Increased volume and pressure → improved DM sensitivity
- ◆ Single anode: drift and avalanche fields coupled
 - ➔ $E \approx V \cdot r_a / r^2 \rightarrow$ **higher voltage** for same field at high r
 - ➔ Challenge to scale detector size or pressure



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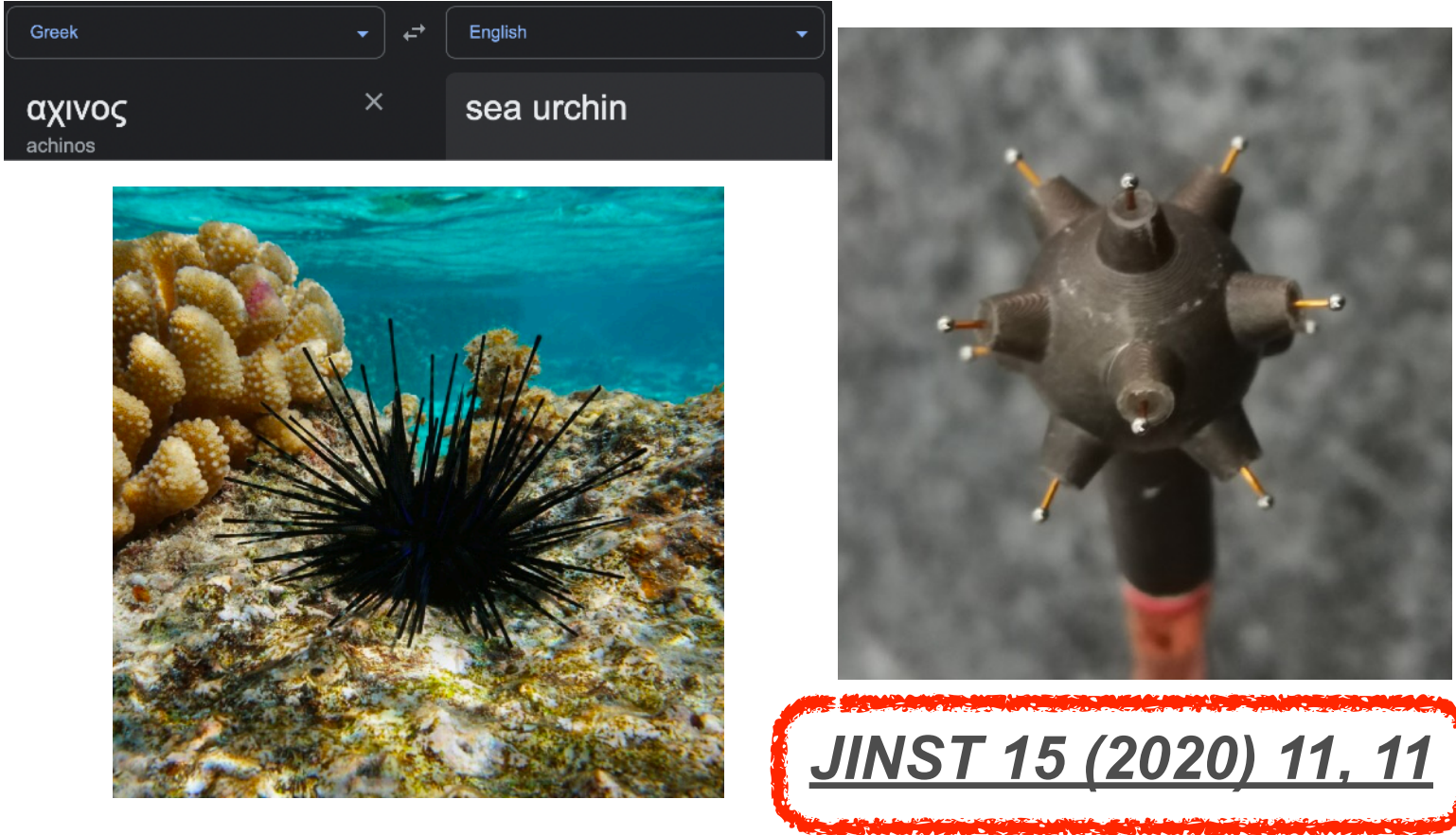
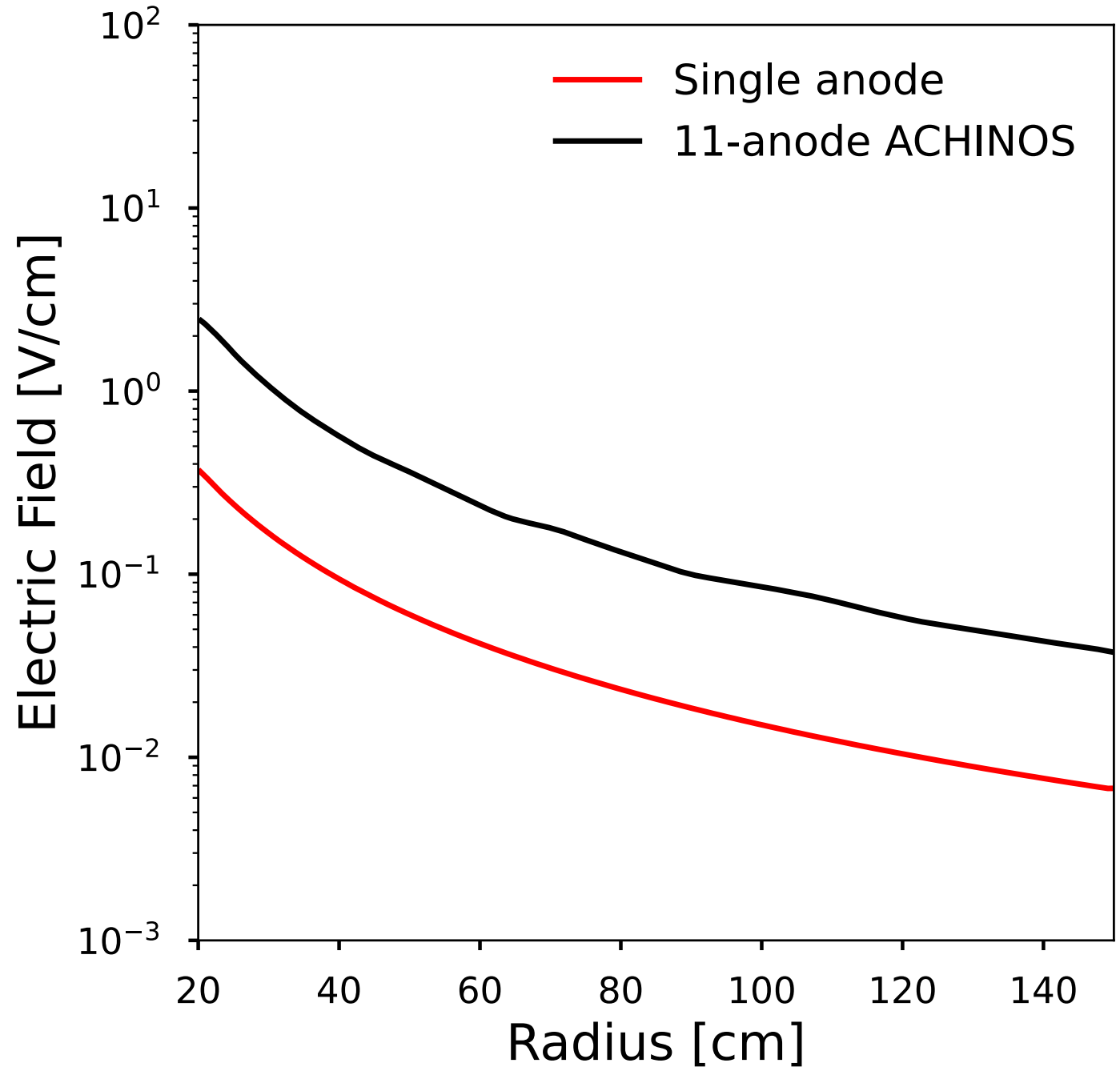
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- ◆ Idea: multiple anodes at fixed radius - **ACHINOS**
 - ➔ Avalanche field: anode radius + voltage
 - ➔ Drift field: Collective field of anodes

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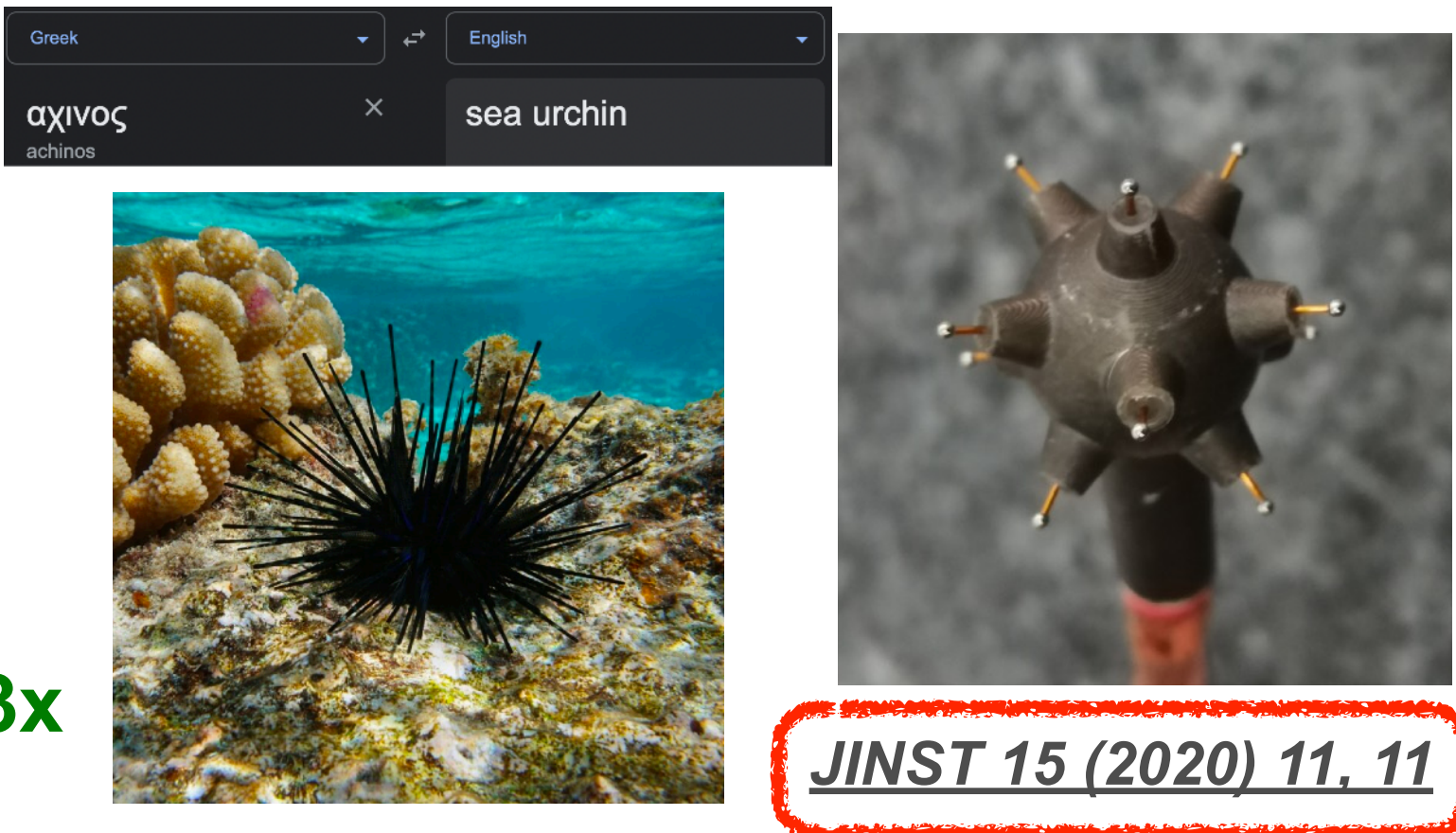
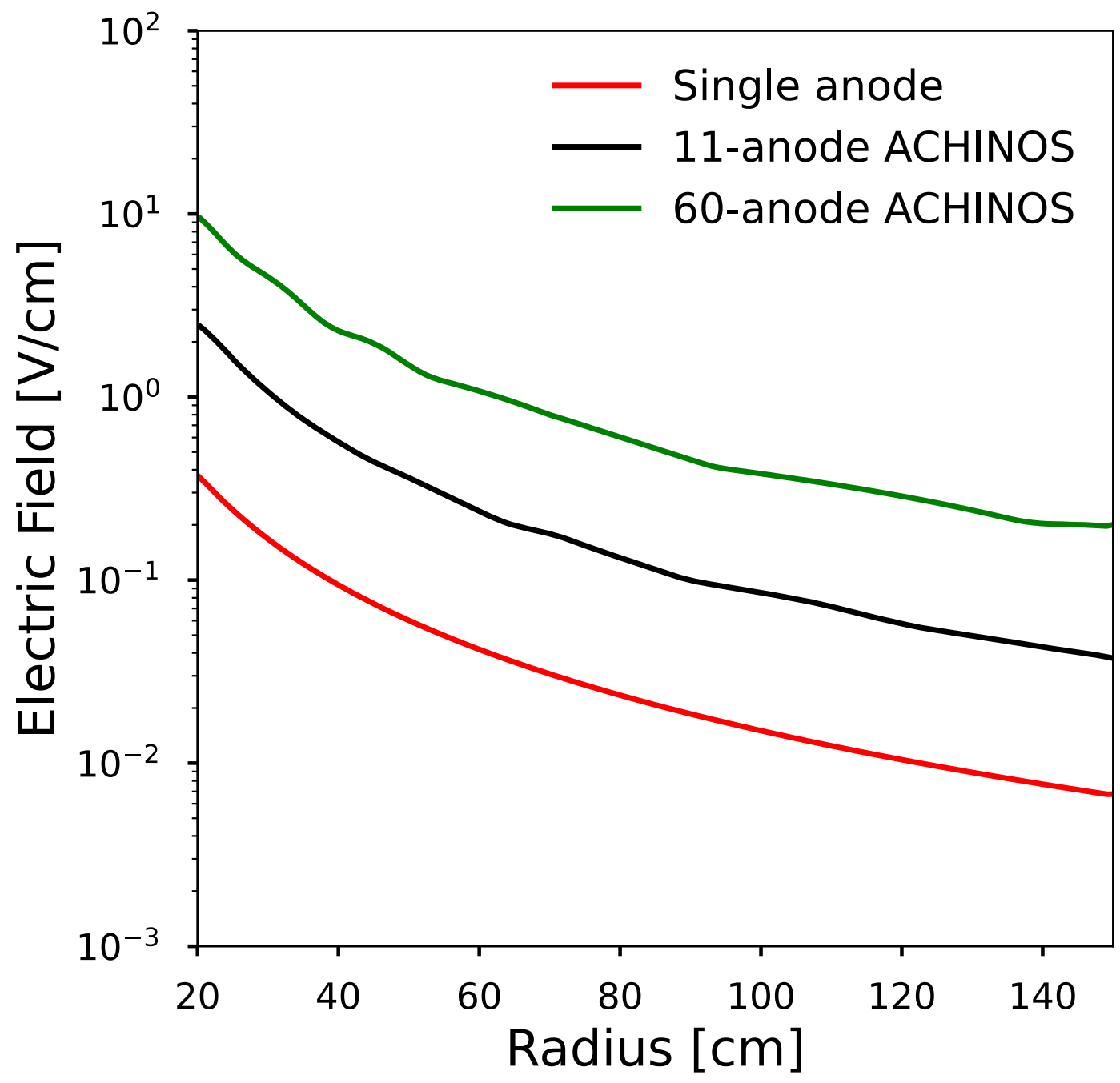
↑ ~7x



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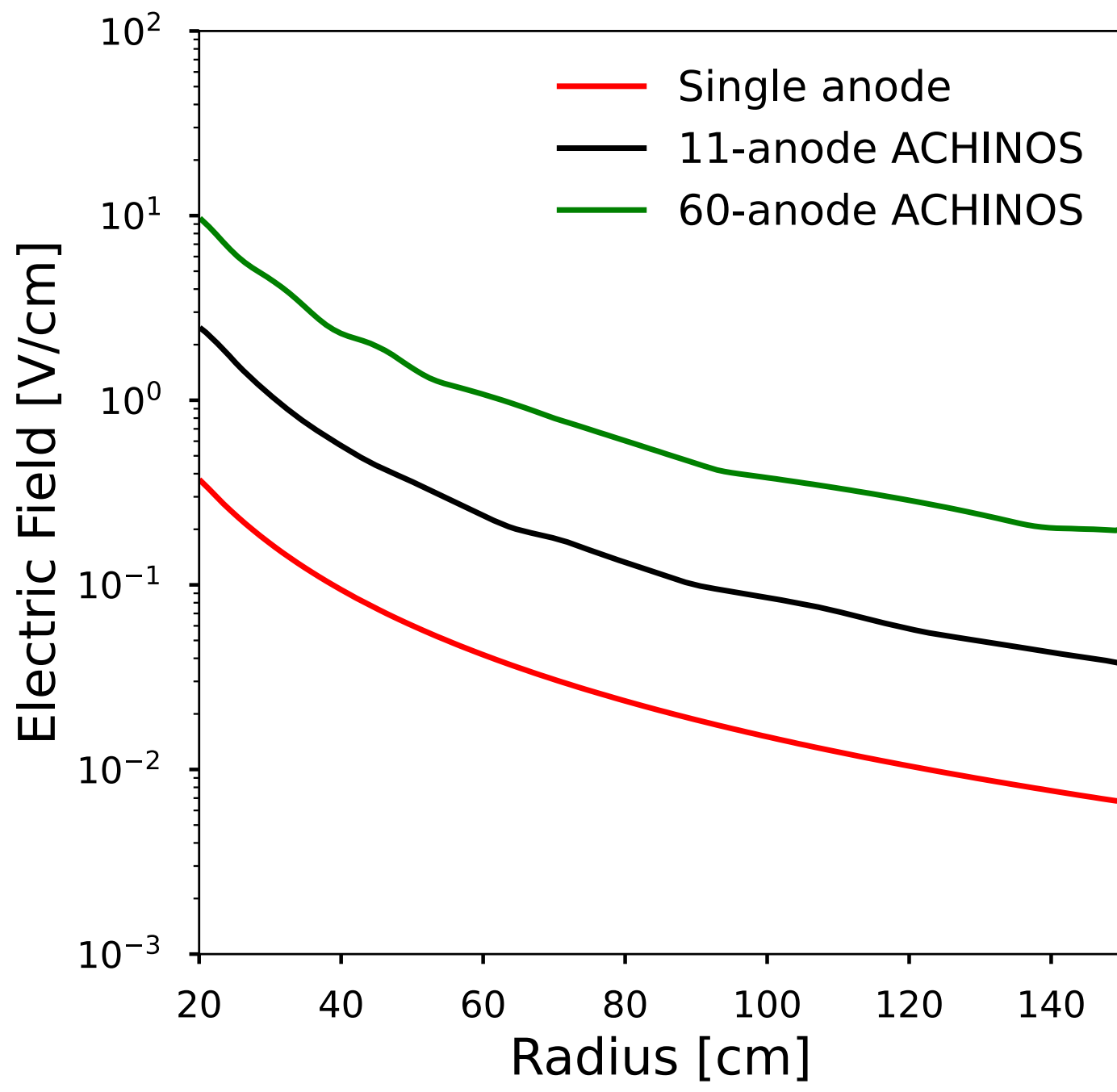
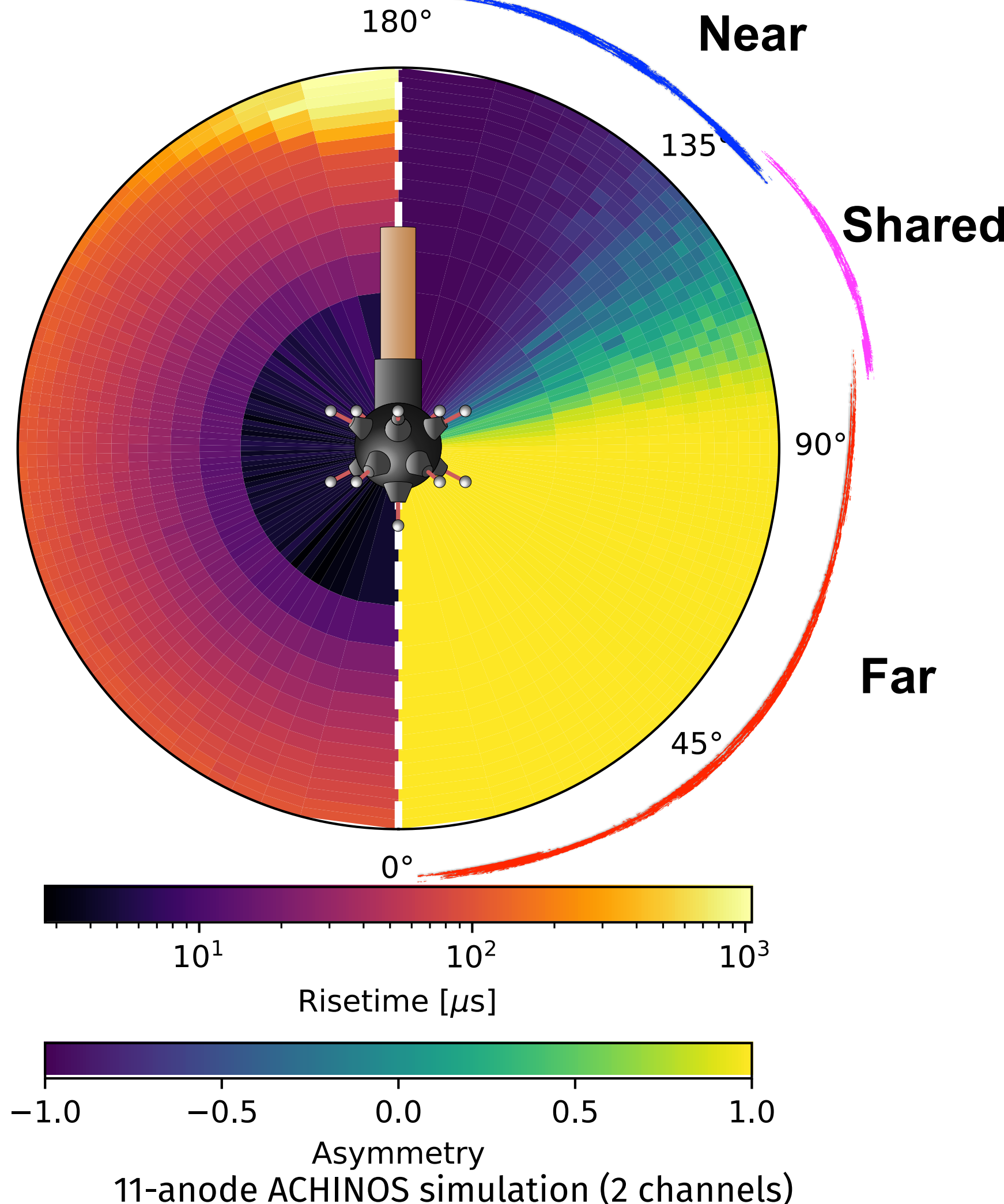
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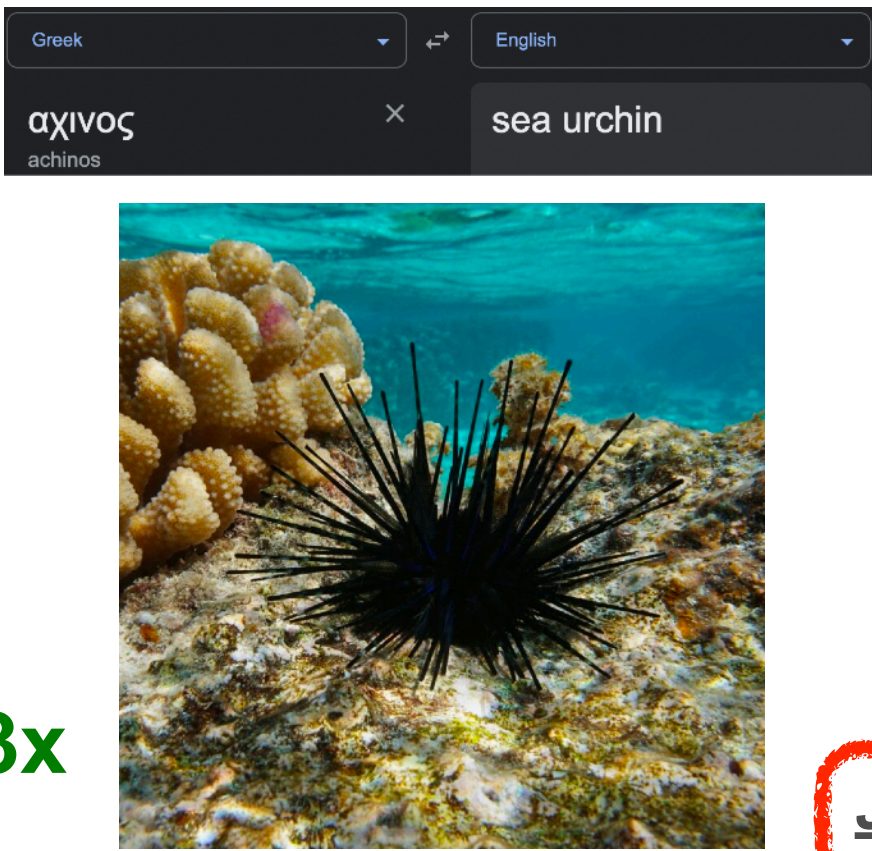
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~33x
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Unlocking the SPC's Potential

- ◆ Previous implementations grouped anodes for read-out
- ◆ Developed capability for **individual anodes read-out**
 - ☑ Improved energy resolution, event localisation,
 - ☑ Extensive simulation study of anode-by-anode gain variations

[See L Millins' Poster \(Monday\)](#)

JINST 19 (2024) 01, P01018

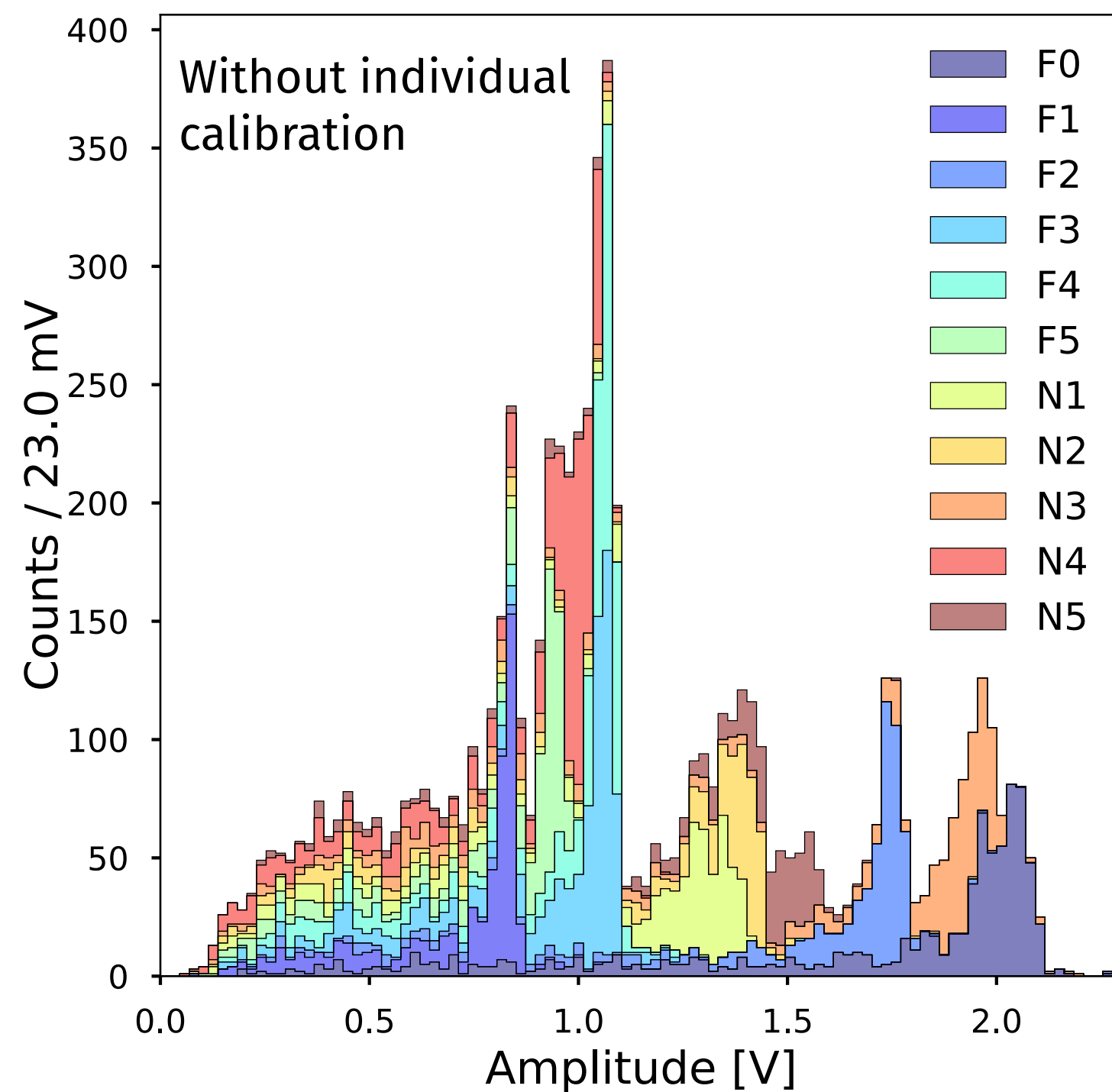
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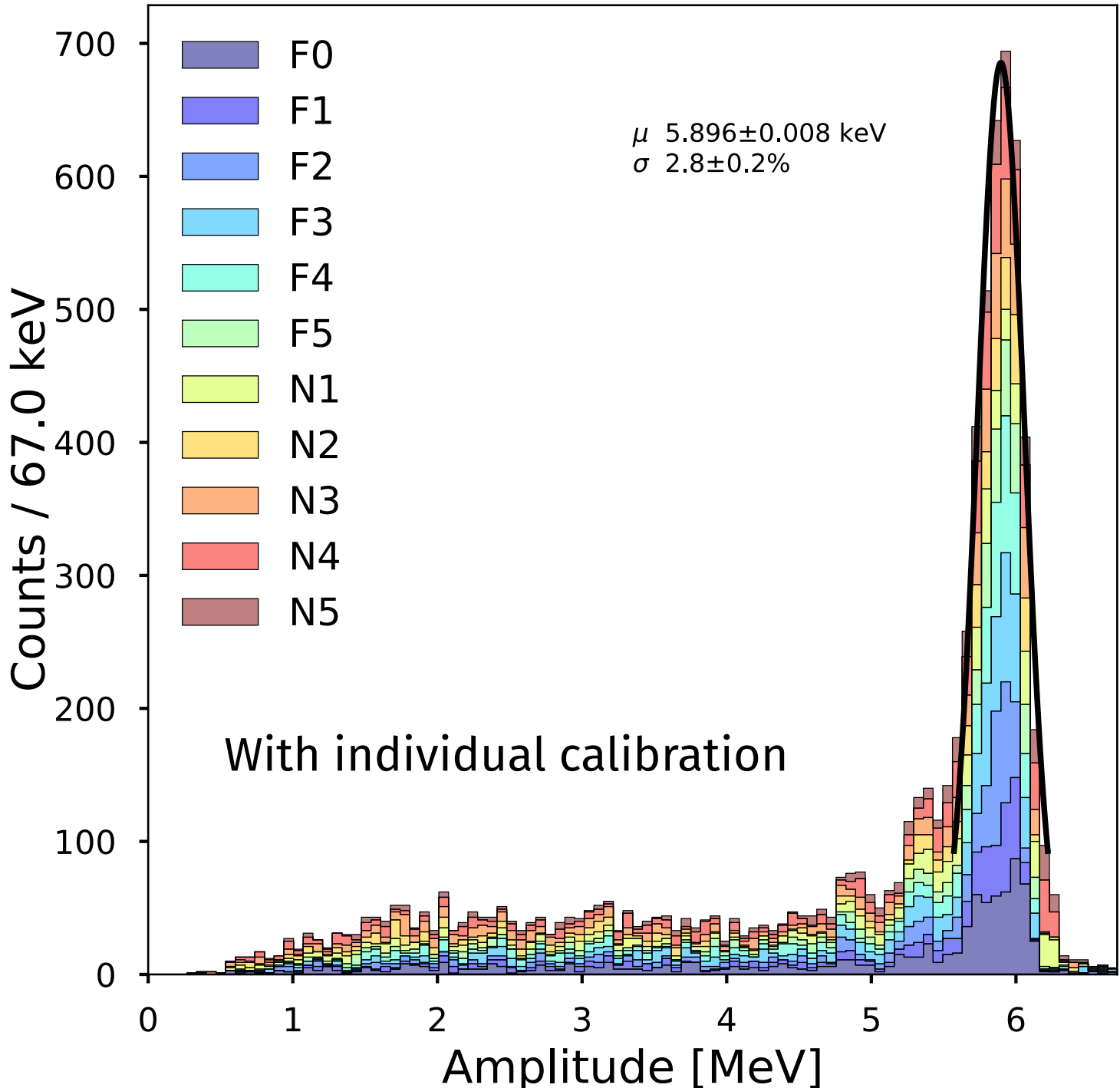
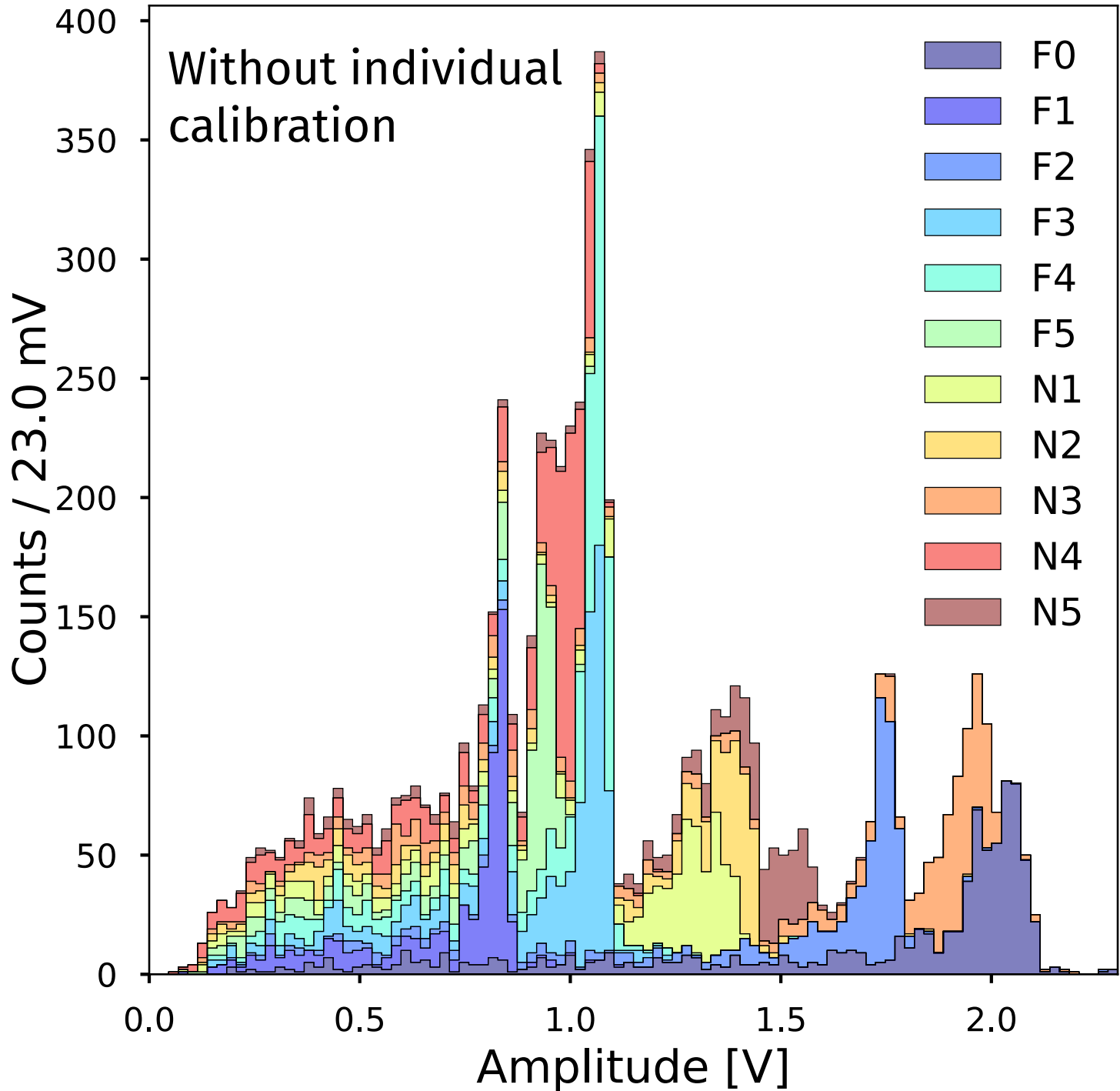
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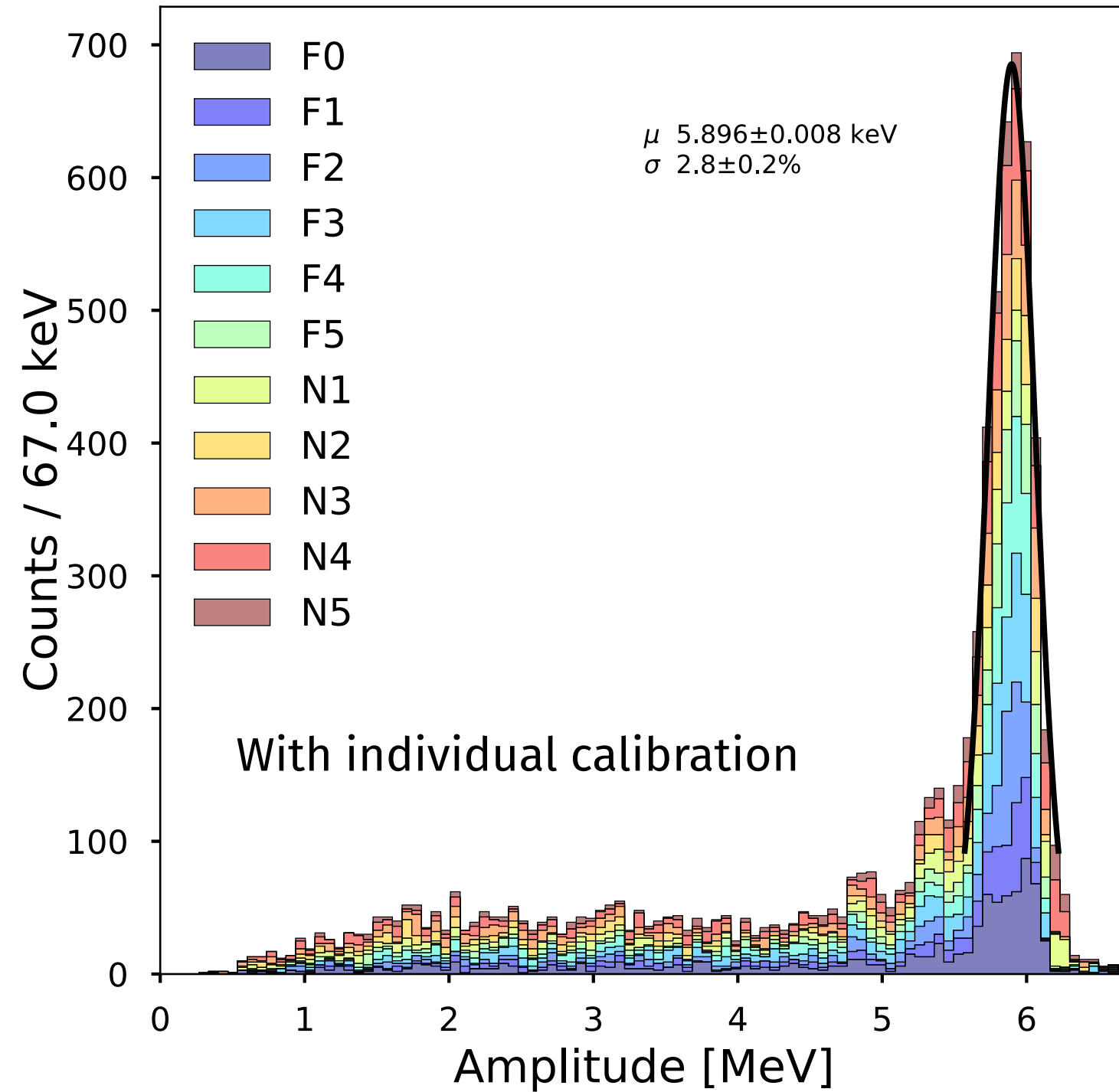
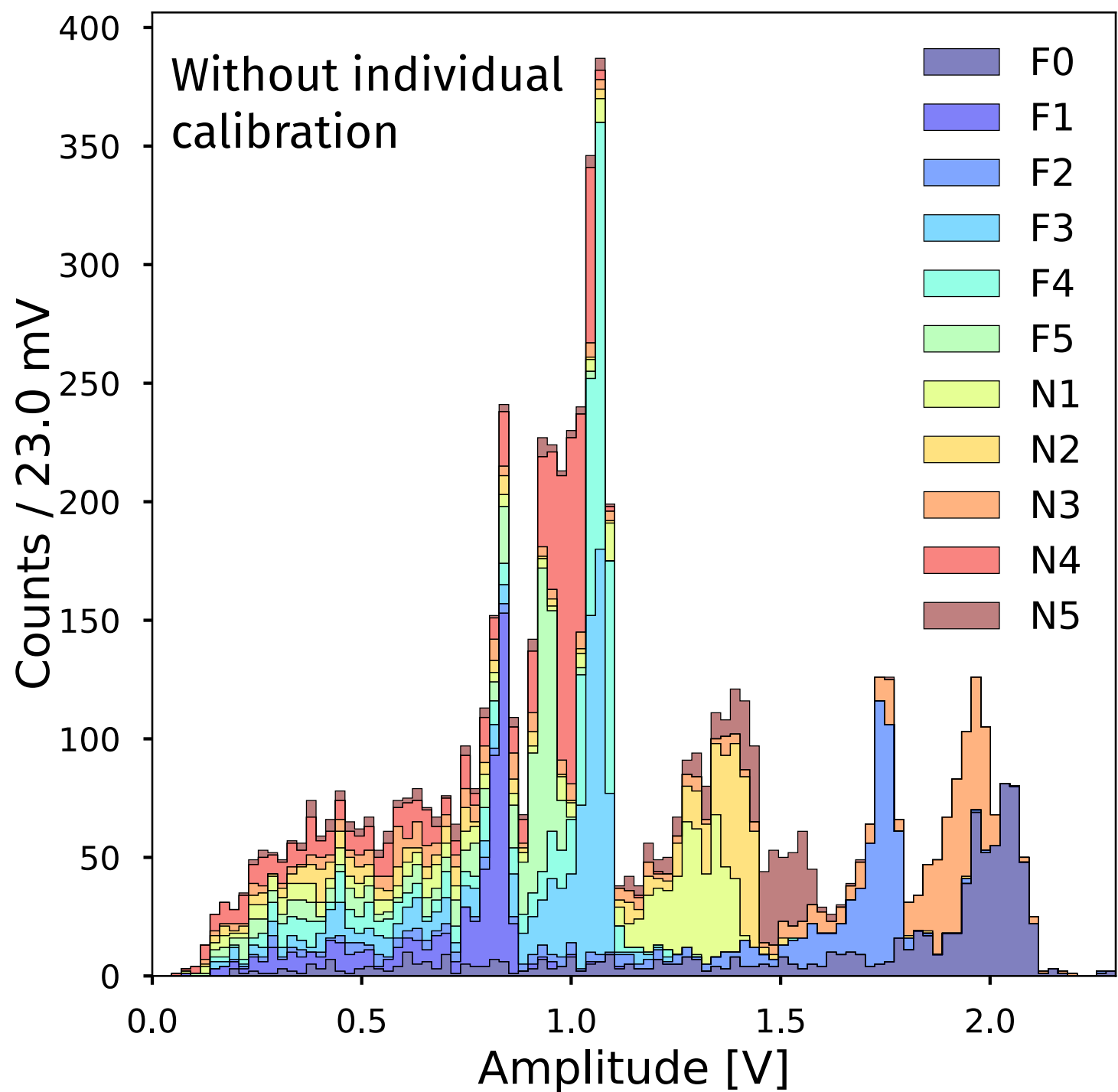
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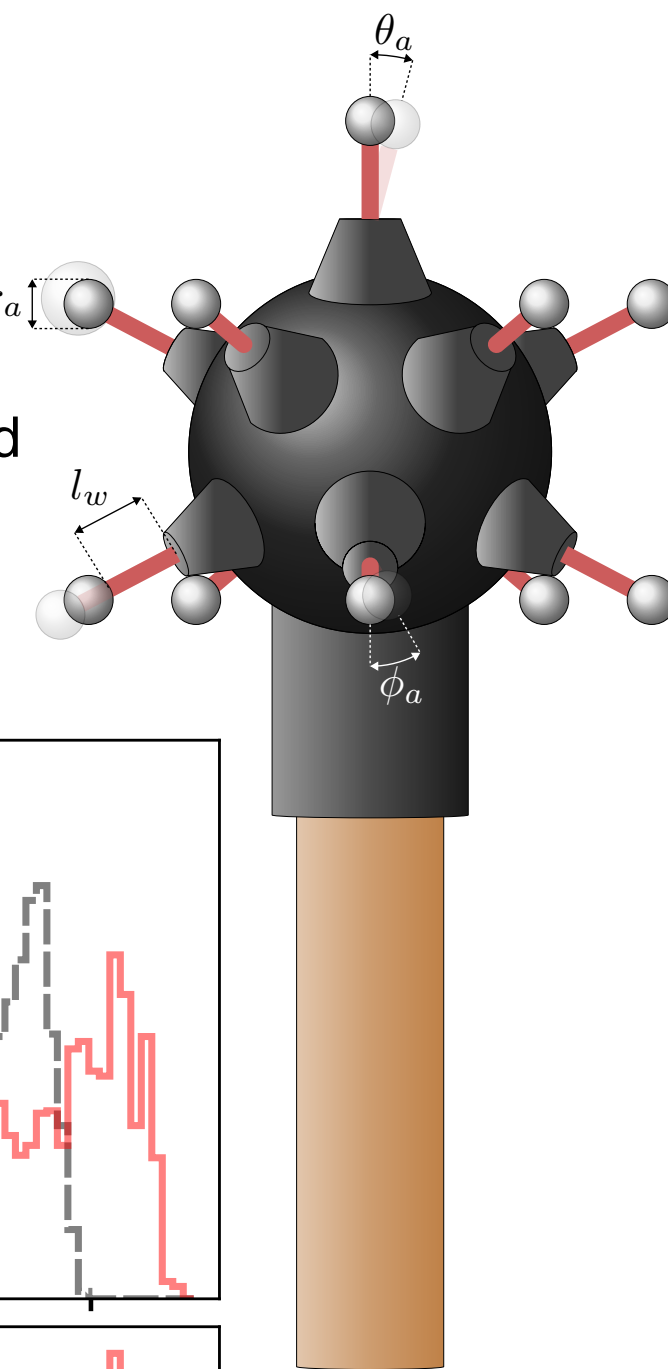
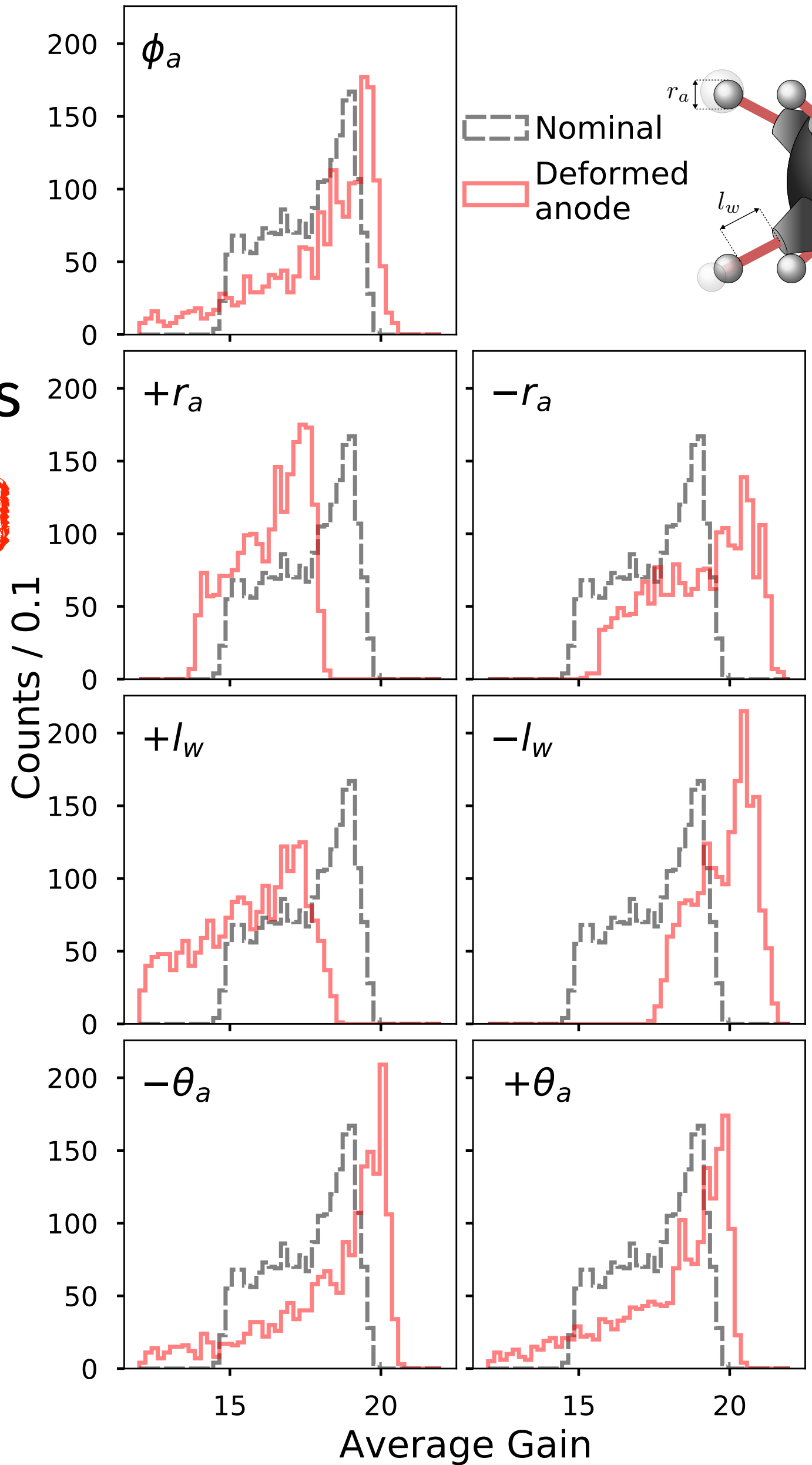
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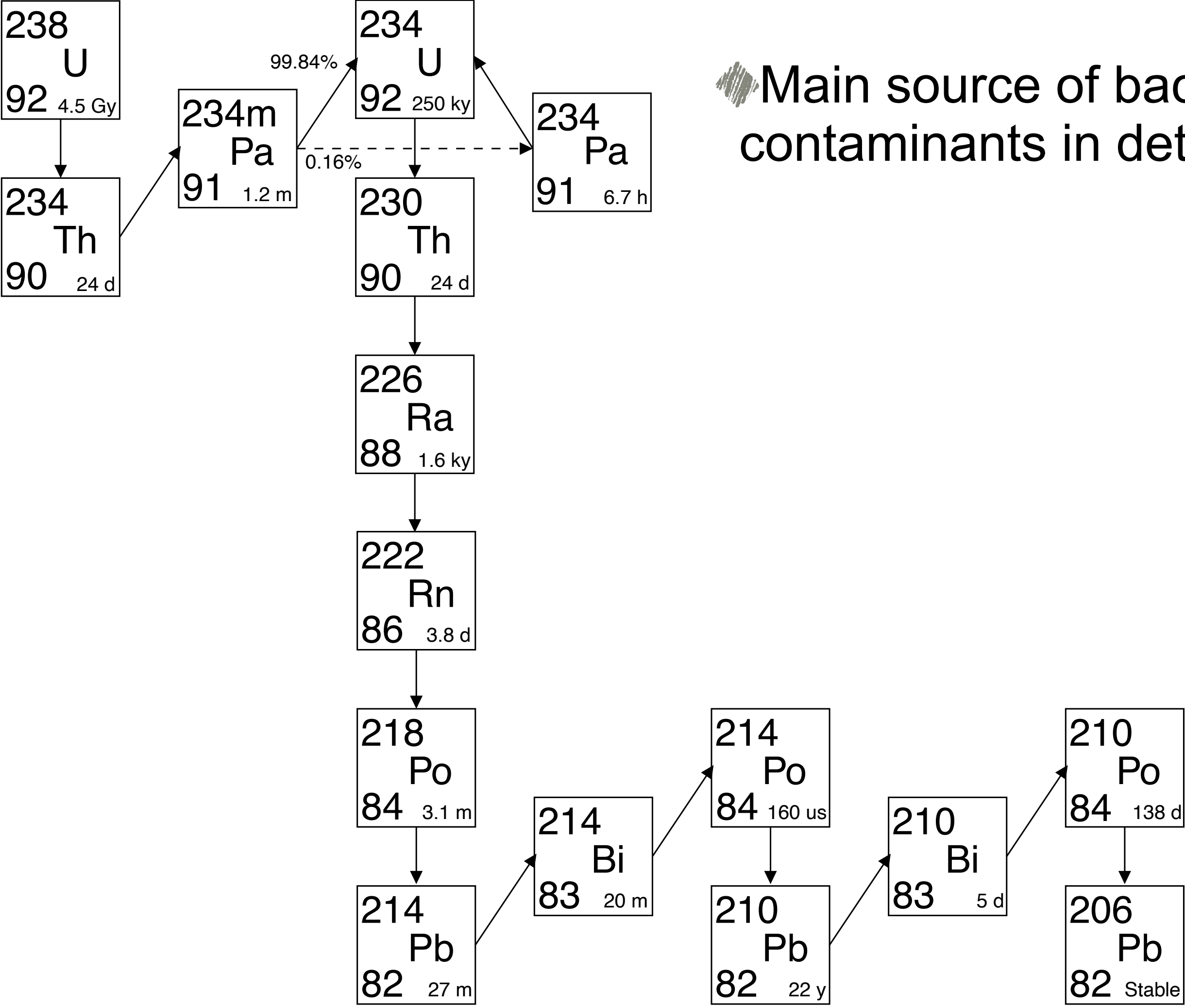
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Simulation

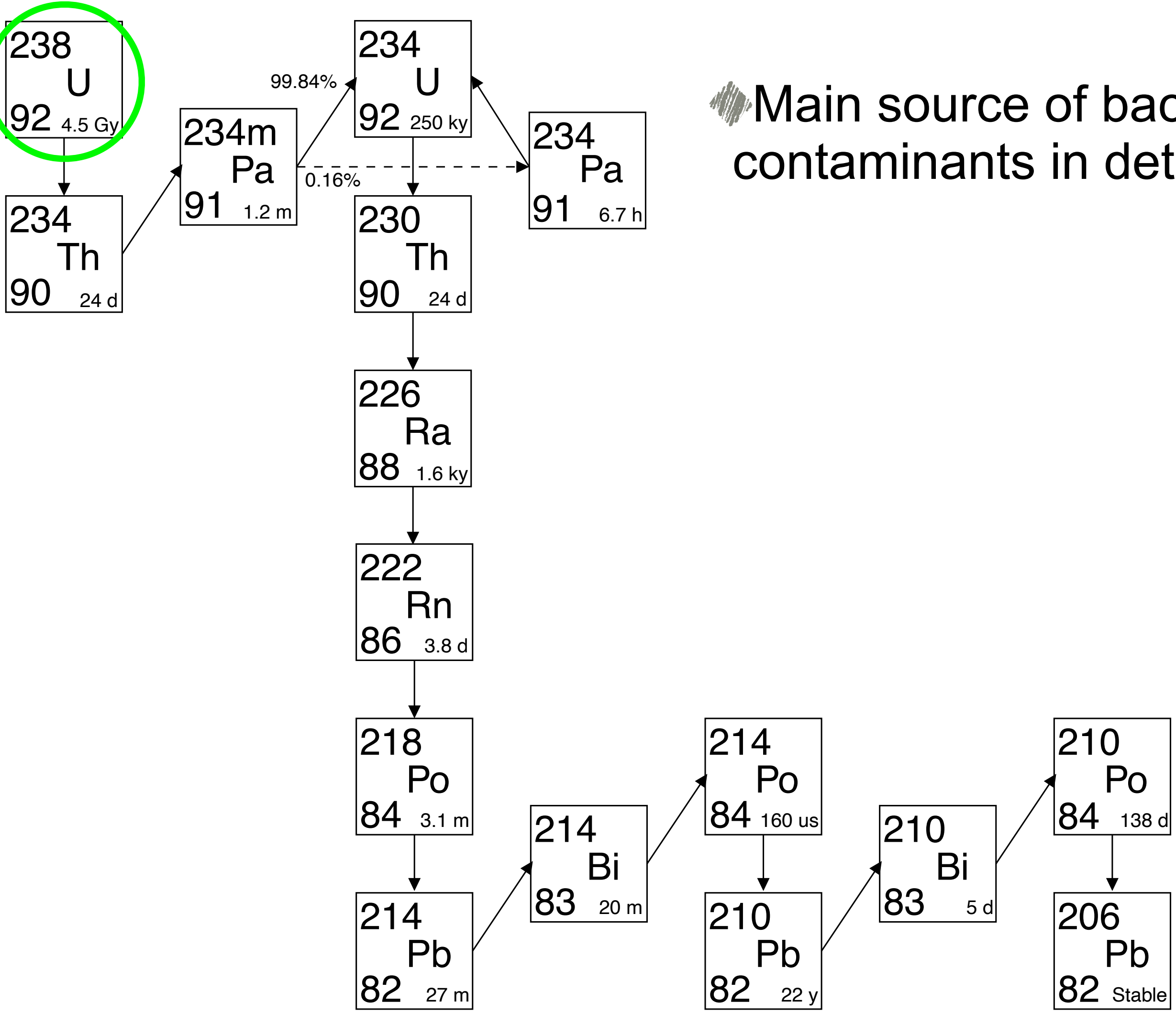


Overcoming Backgrounds in Copper



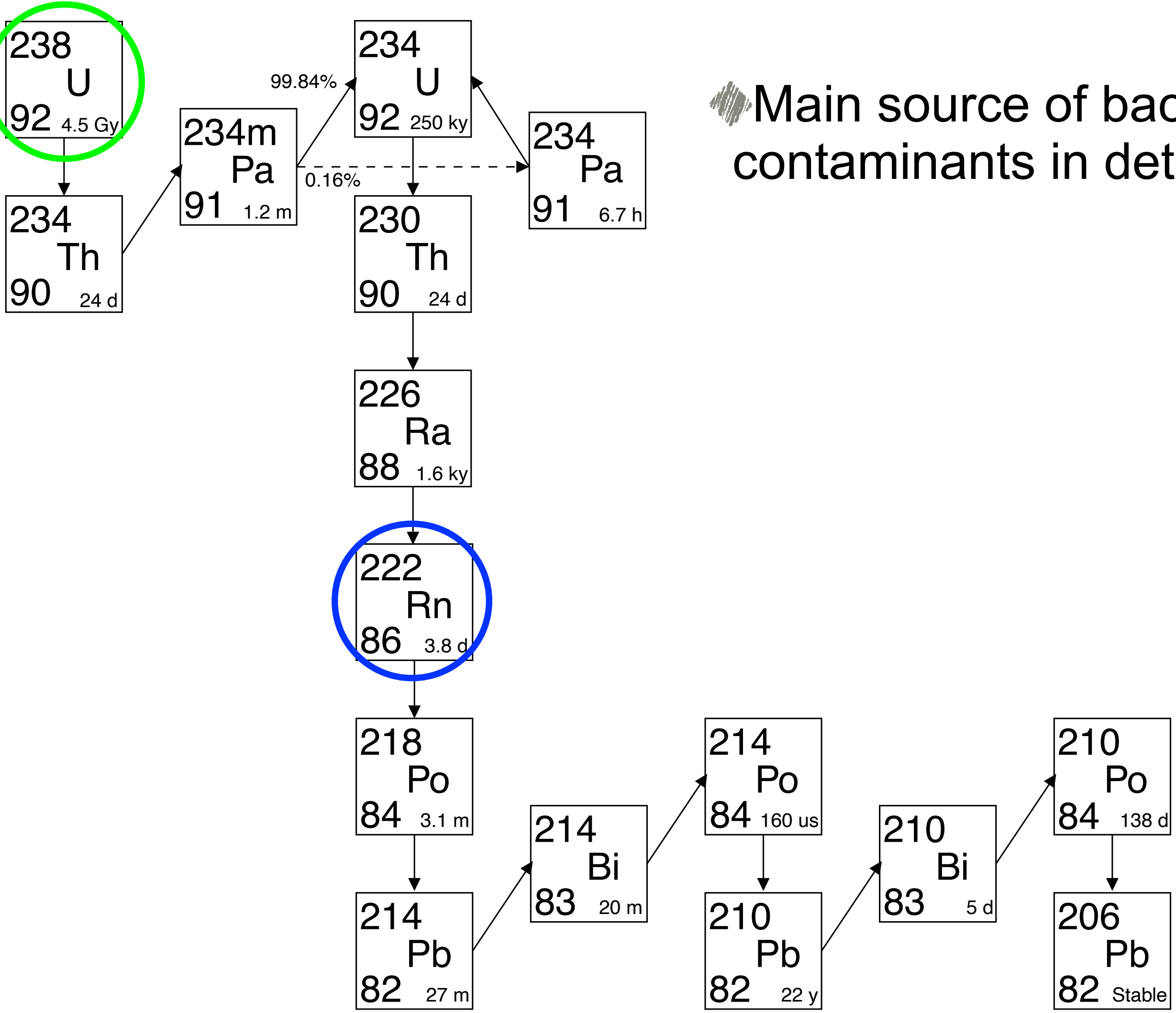
Main source of background is contaminants in detector copper

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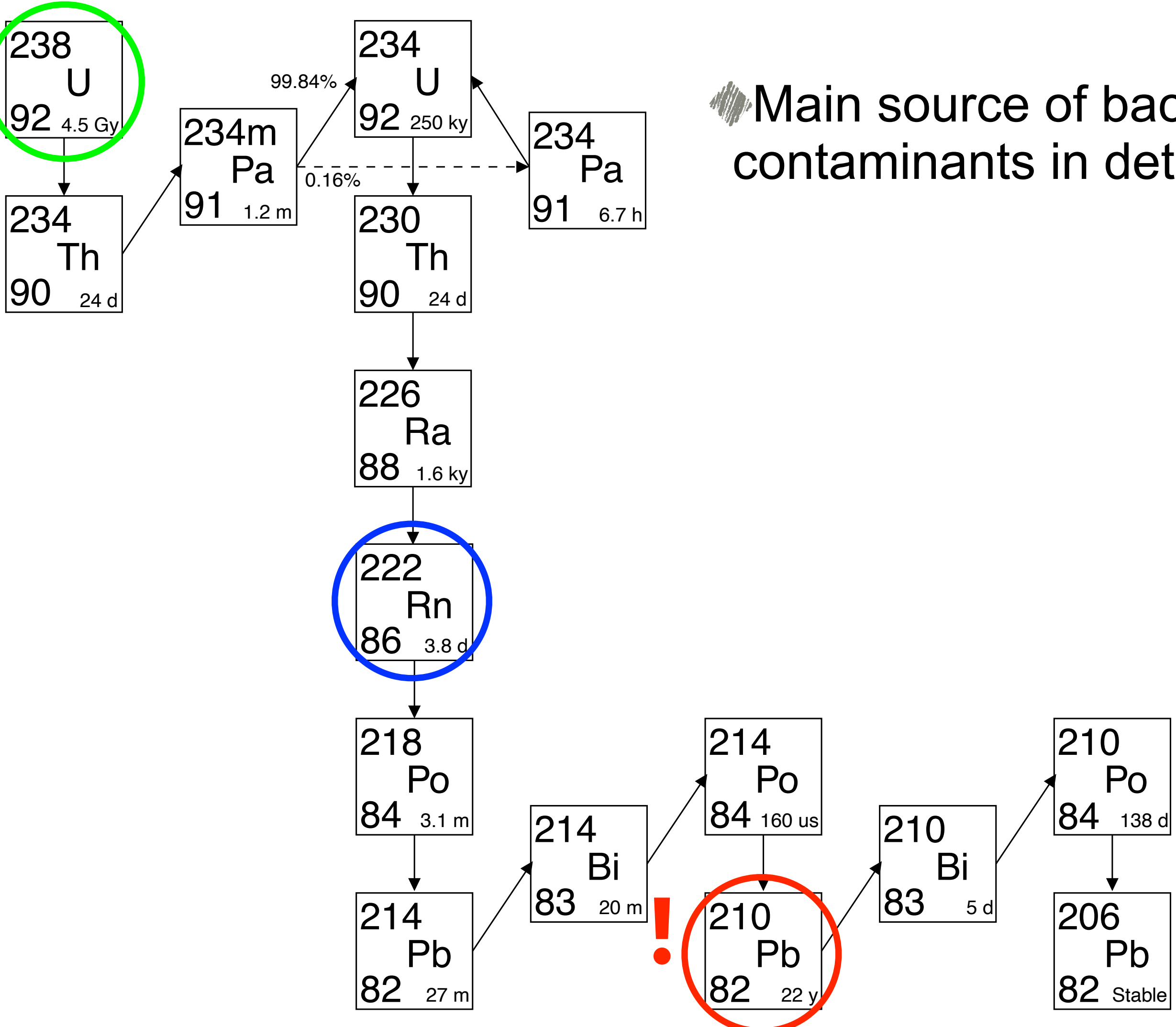
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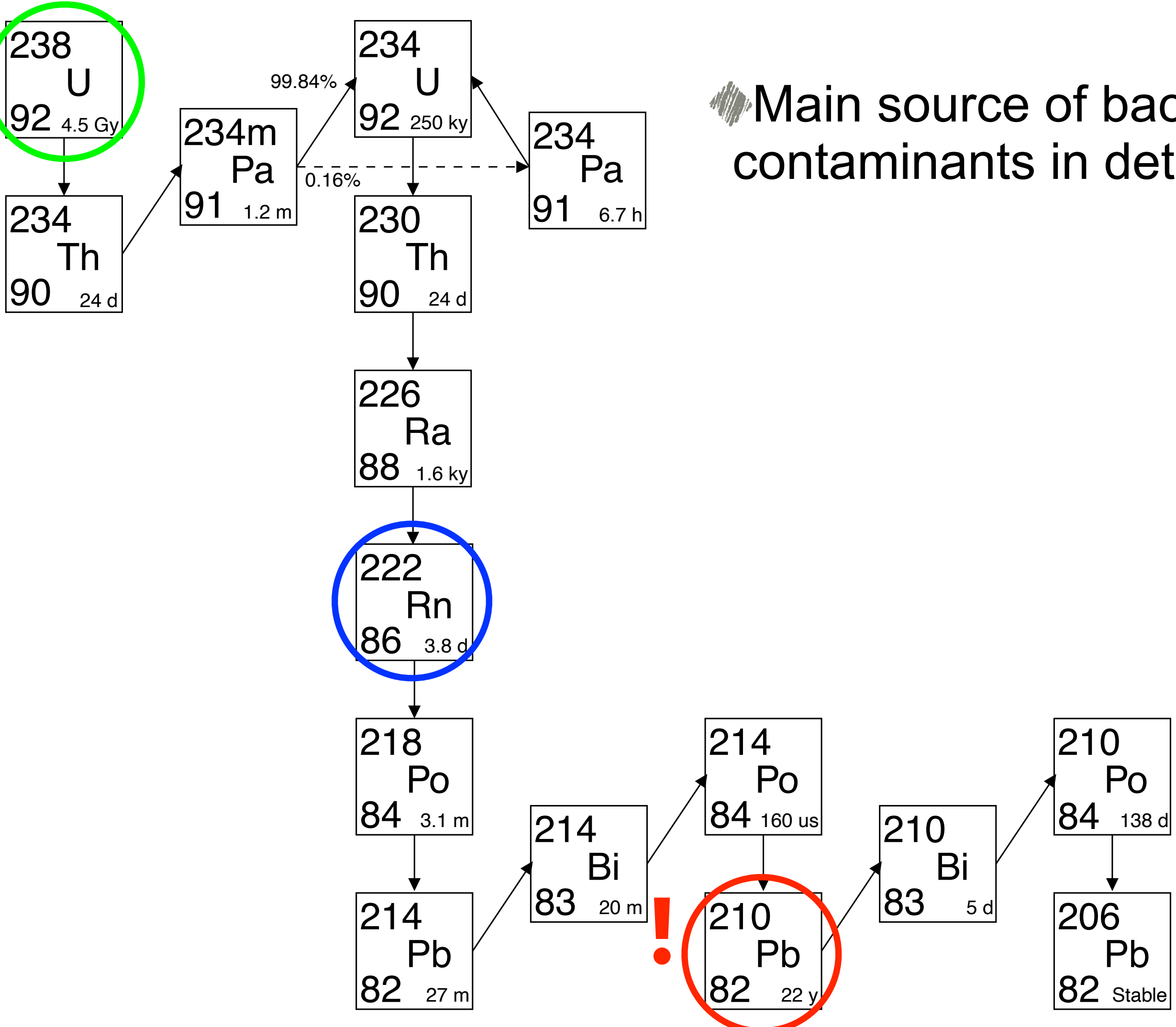
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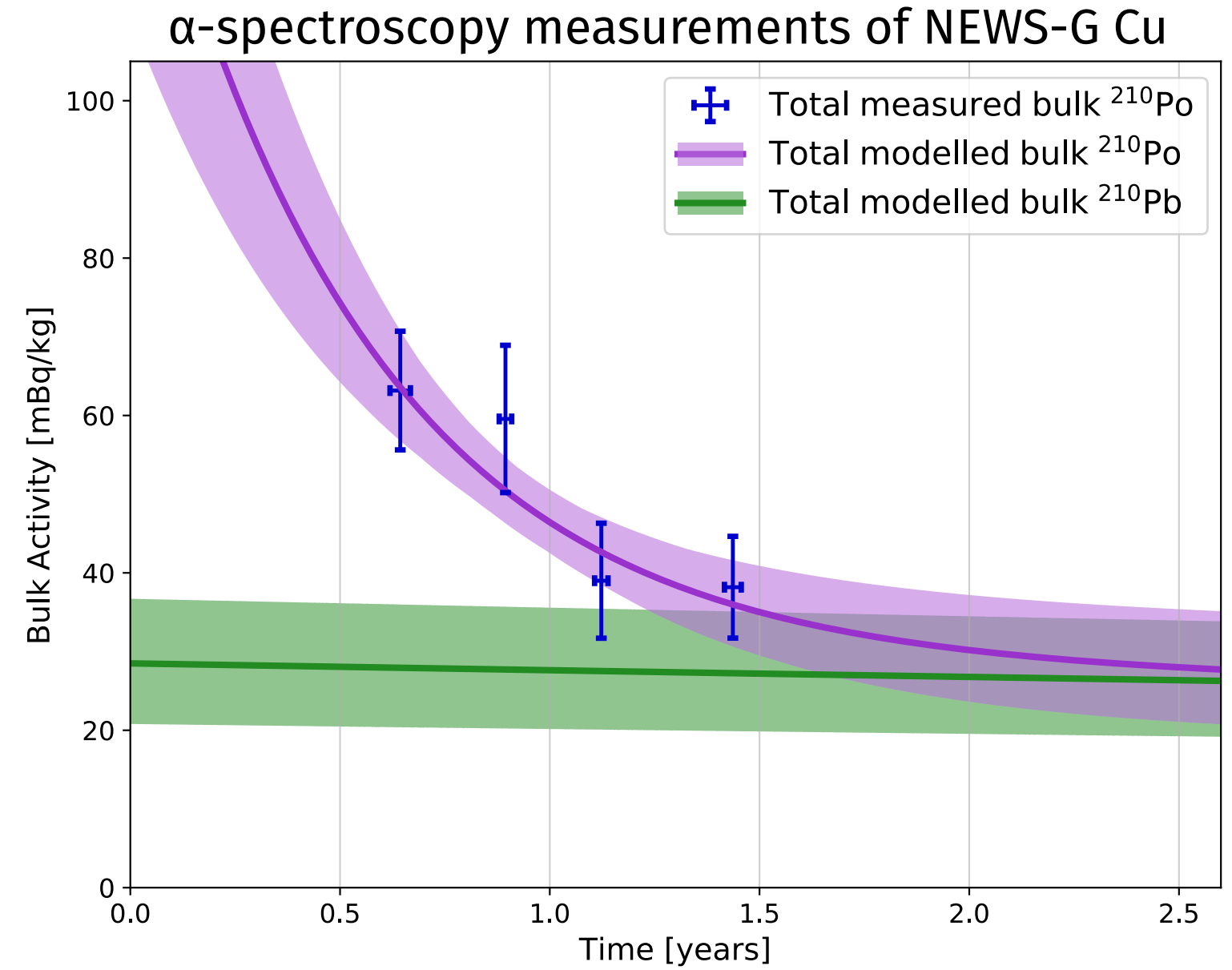


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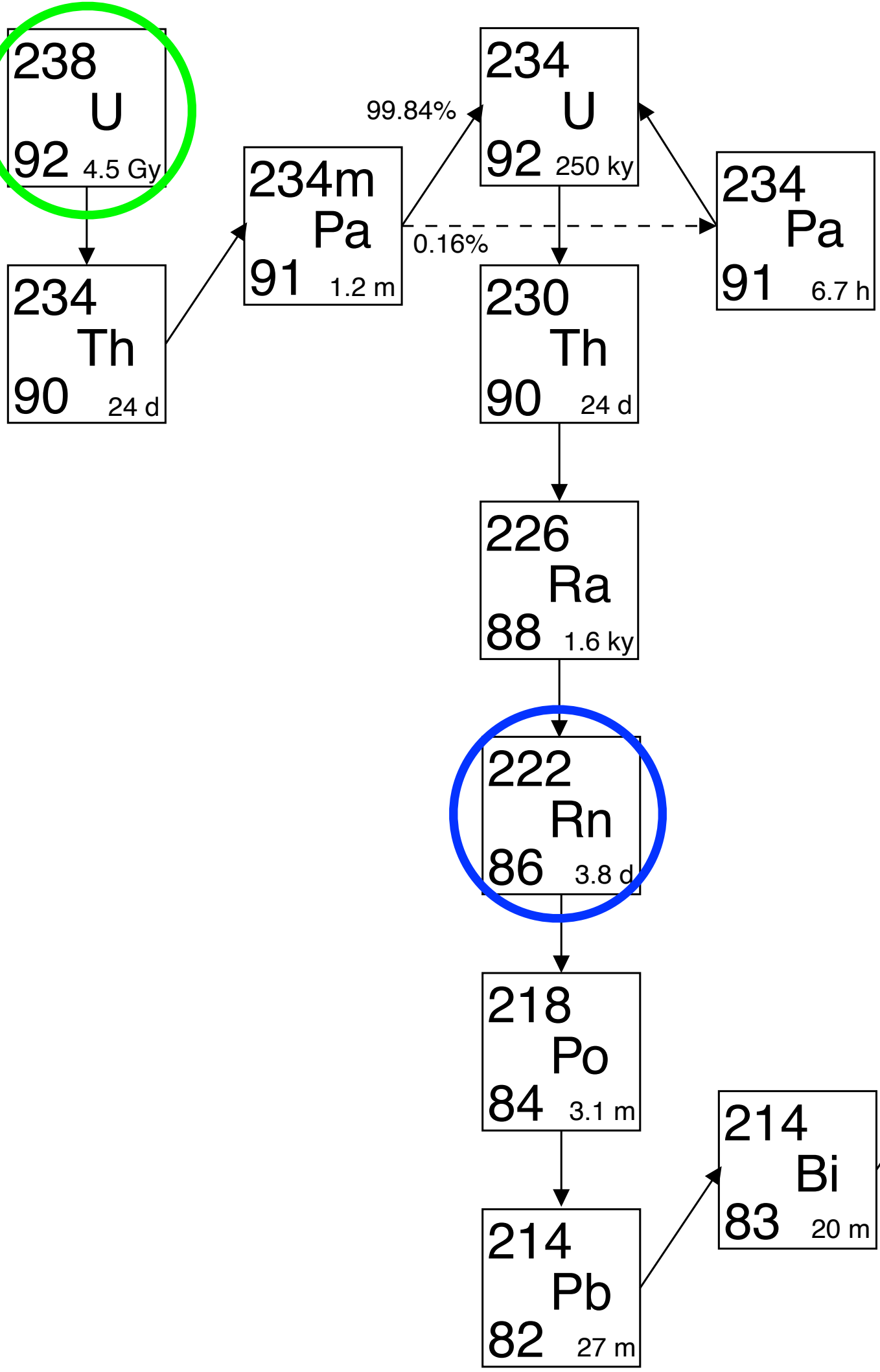
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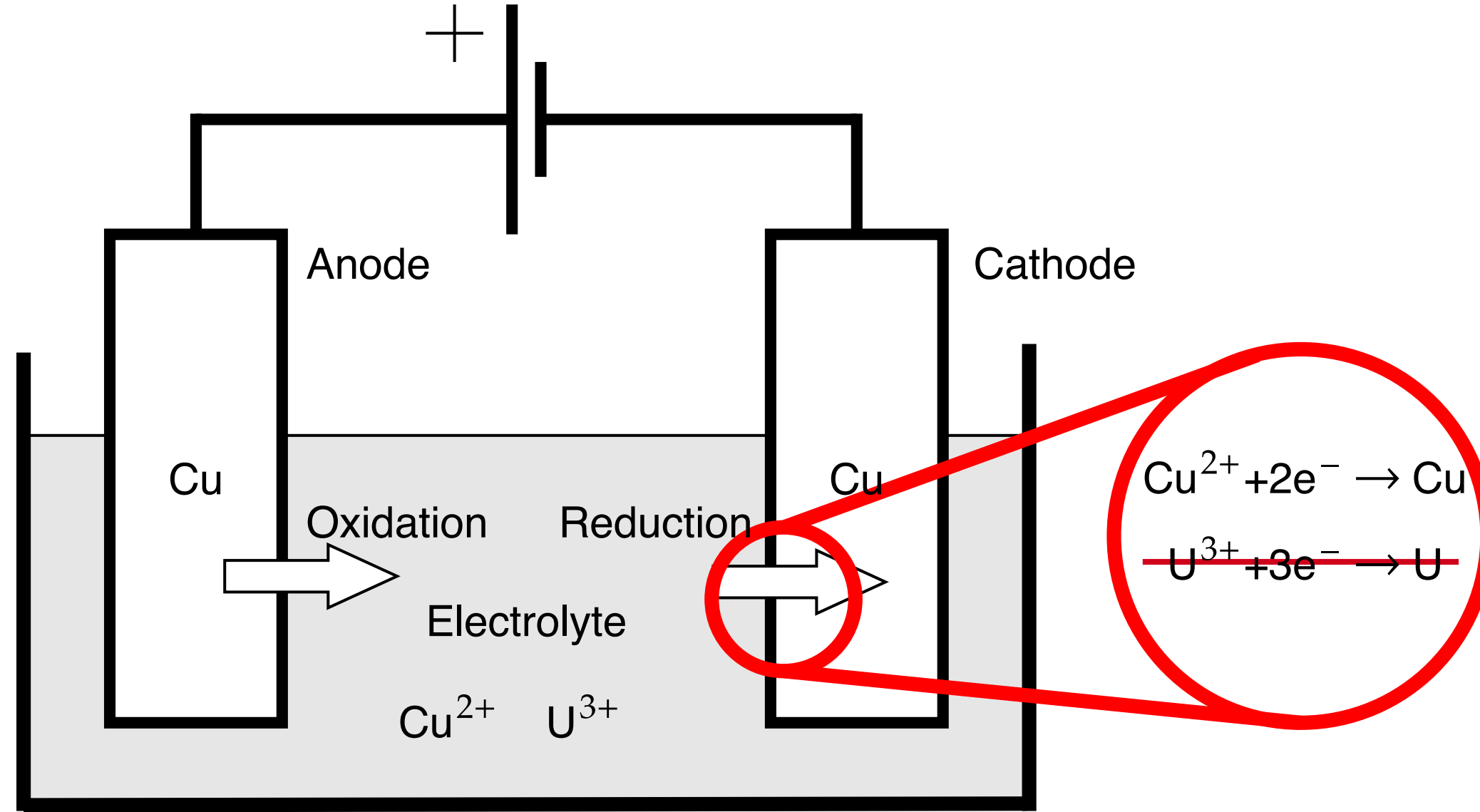
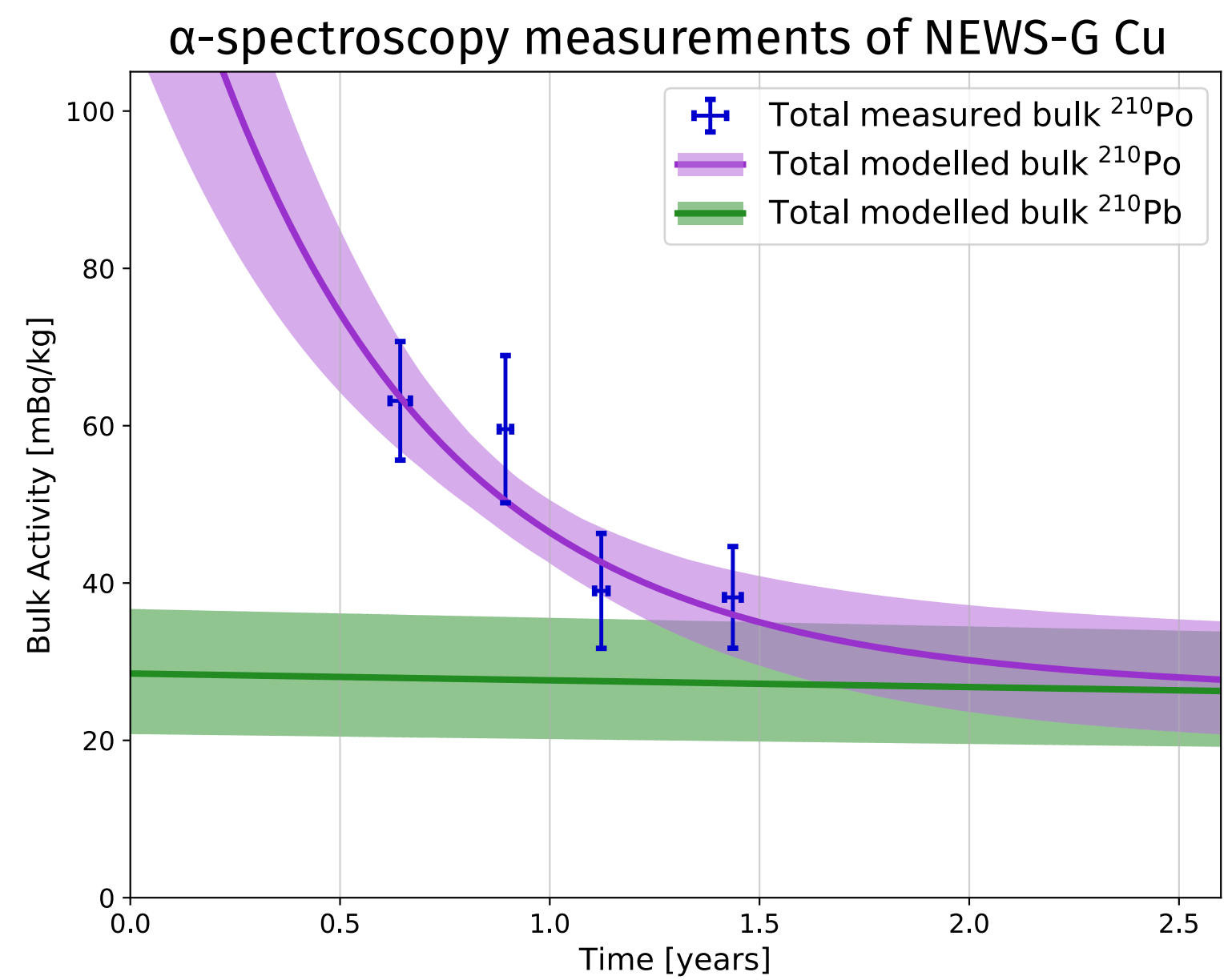
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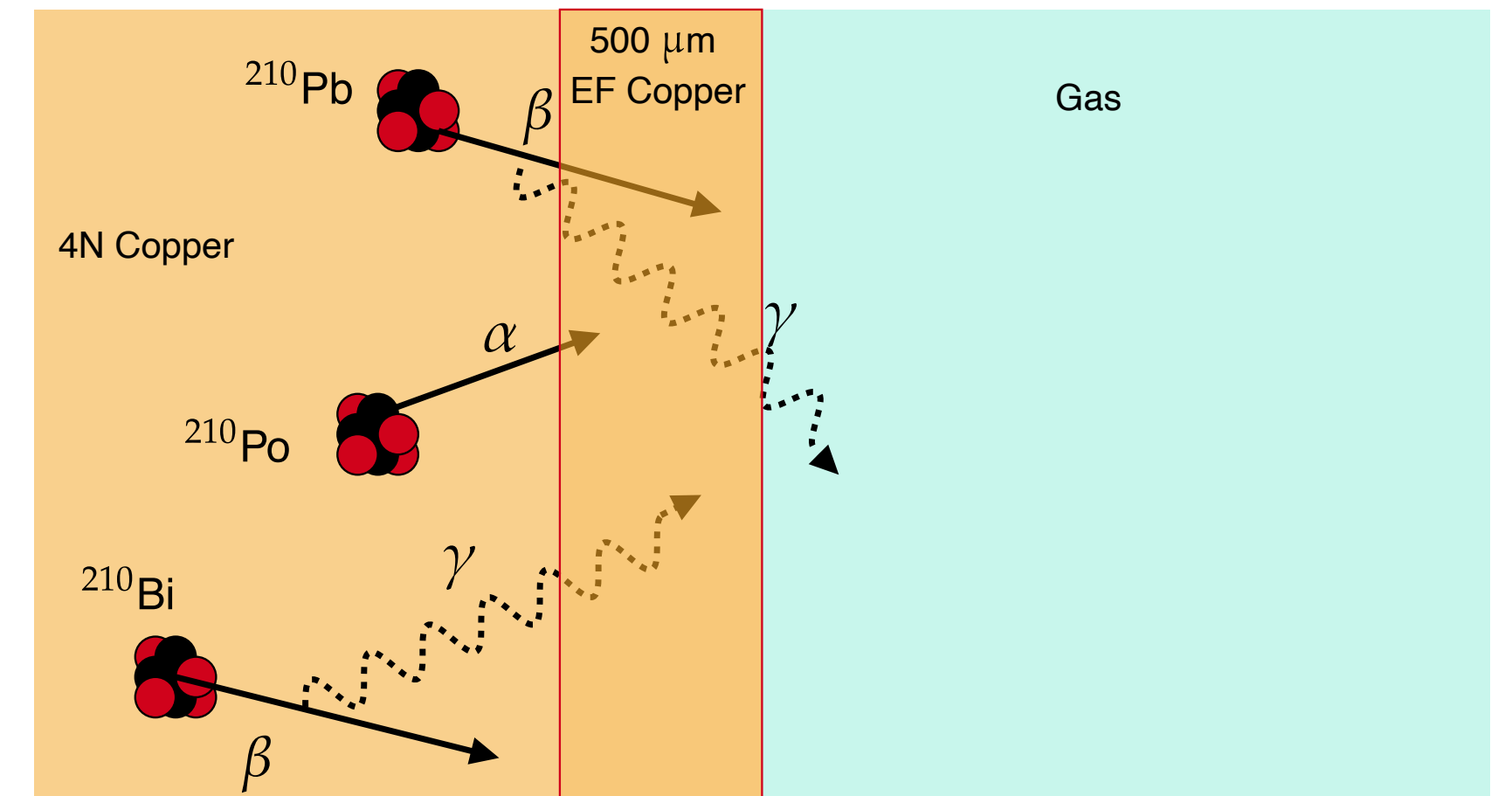


- Main source of background is contaminants in detector copper
- Additive-free, **electroforming**
- 'High reduction potential' of copper
→ Preferentially deposited



Ultra-Pure Copper Electroforming

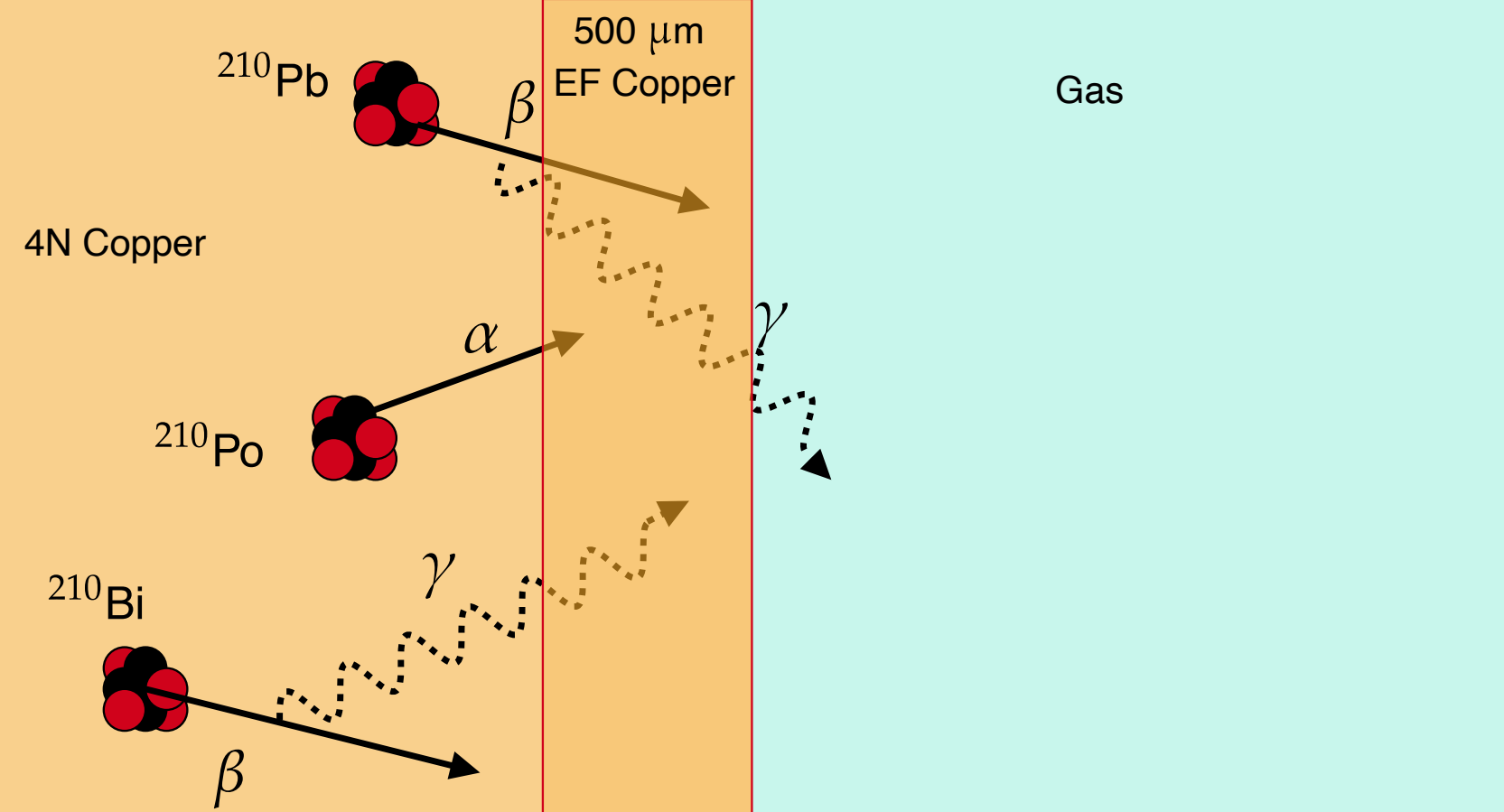
- ◆ **500 μm electroplated layer** to NEWS-G detector inner surface
- ◆ Demonstrated potential to electroform full detector on feasible time scale



Ultra-Pure Copper Electroforming



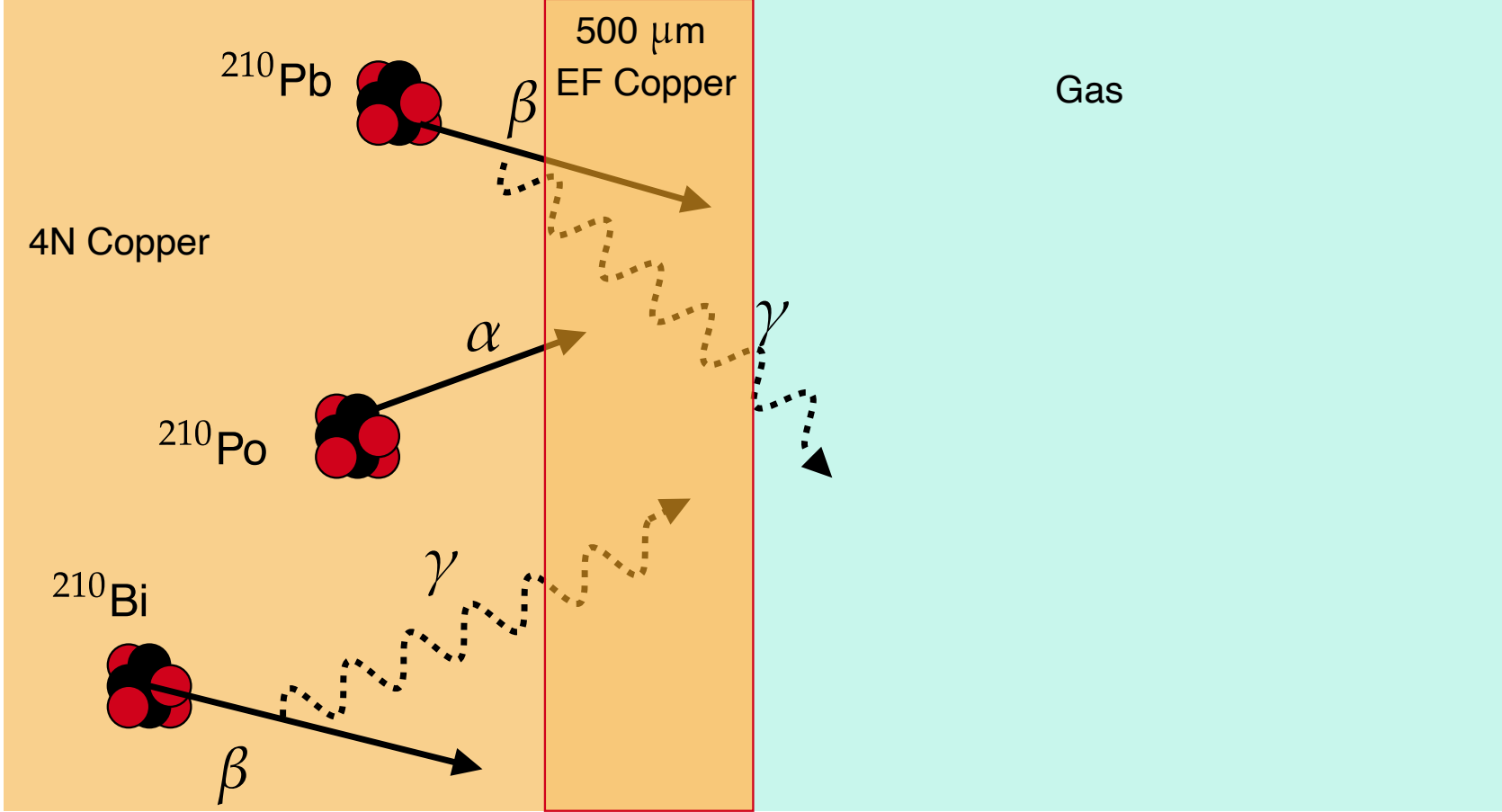
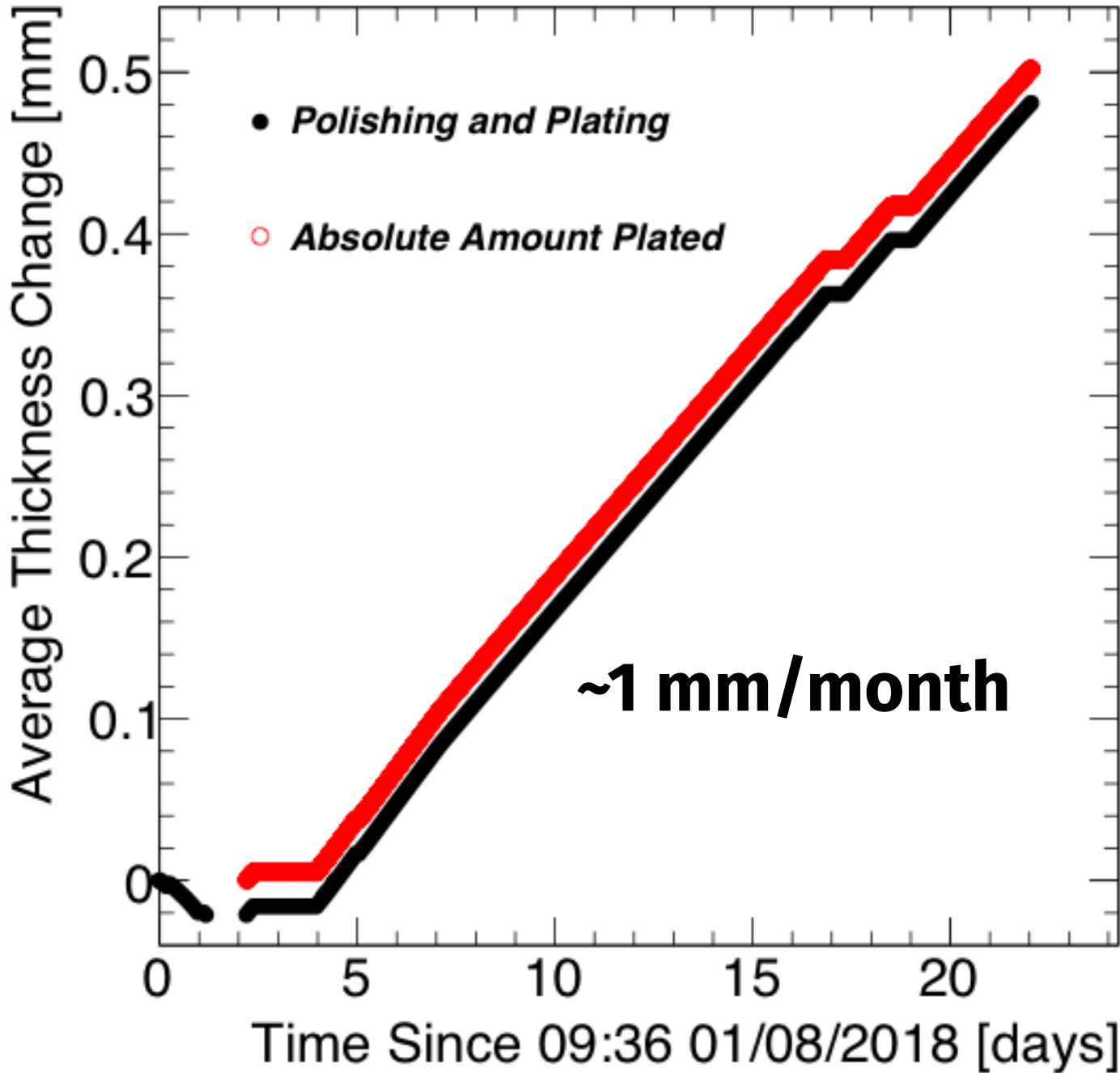
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Ultra-Pure Copper Electroforming



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ICP-MS Assay

Sample	Weight [g]	^{232}Th [$\mu\text{Bq kg}^{-1}$]	^{238}U [$\mu\text{Bq kg}^{-1}$]
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

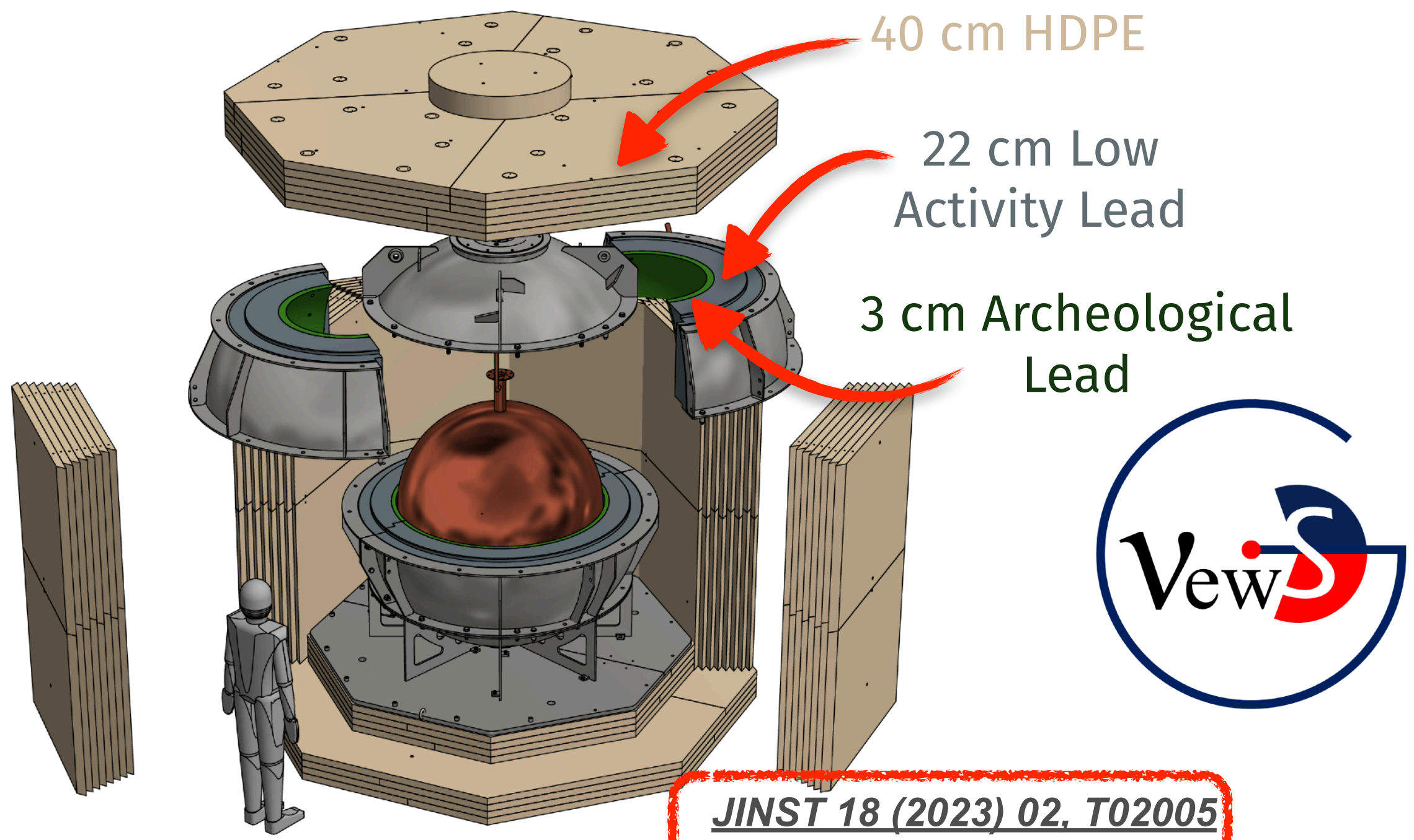
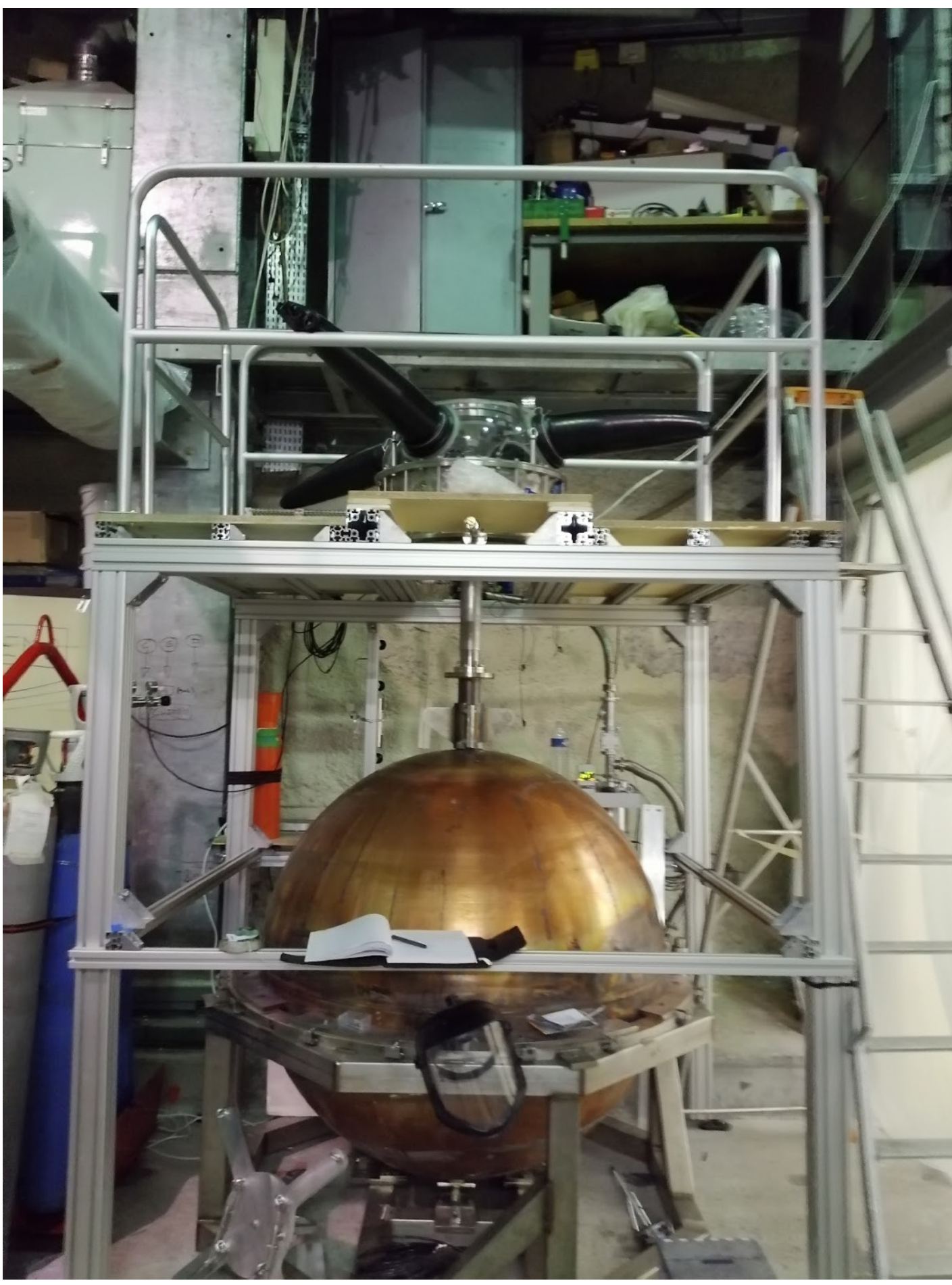
NIMA 988 (2021) 164844

SNOGLOBE in SNOLAB

- ❖ \varnothing 140 cm detector **4N (99.99% pure)** Aurubis copper
 - ➔ Electroplated internal layer
- ❖ Constructed and tested in LSM, France
- ✓ Commissioning data analysis finalising (CH₄)

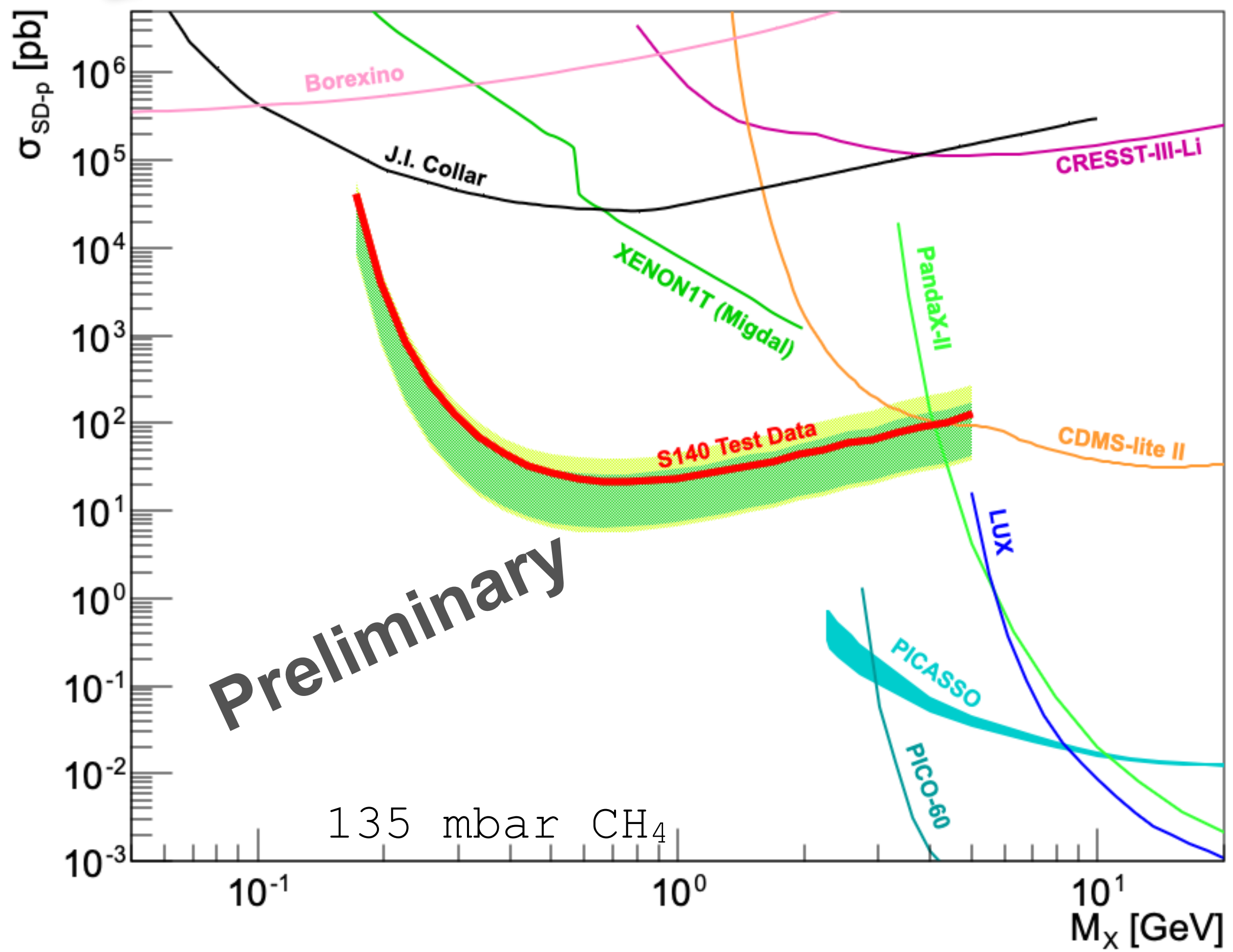
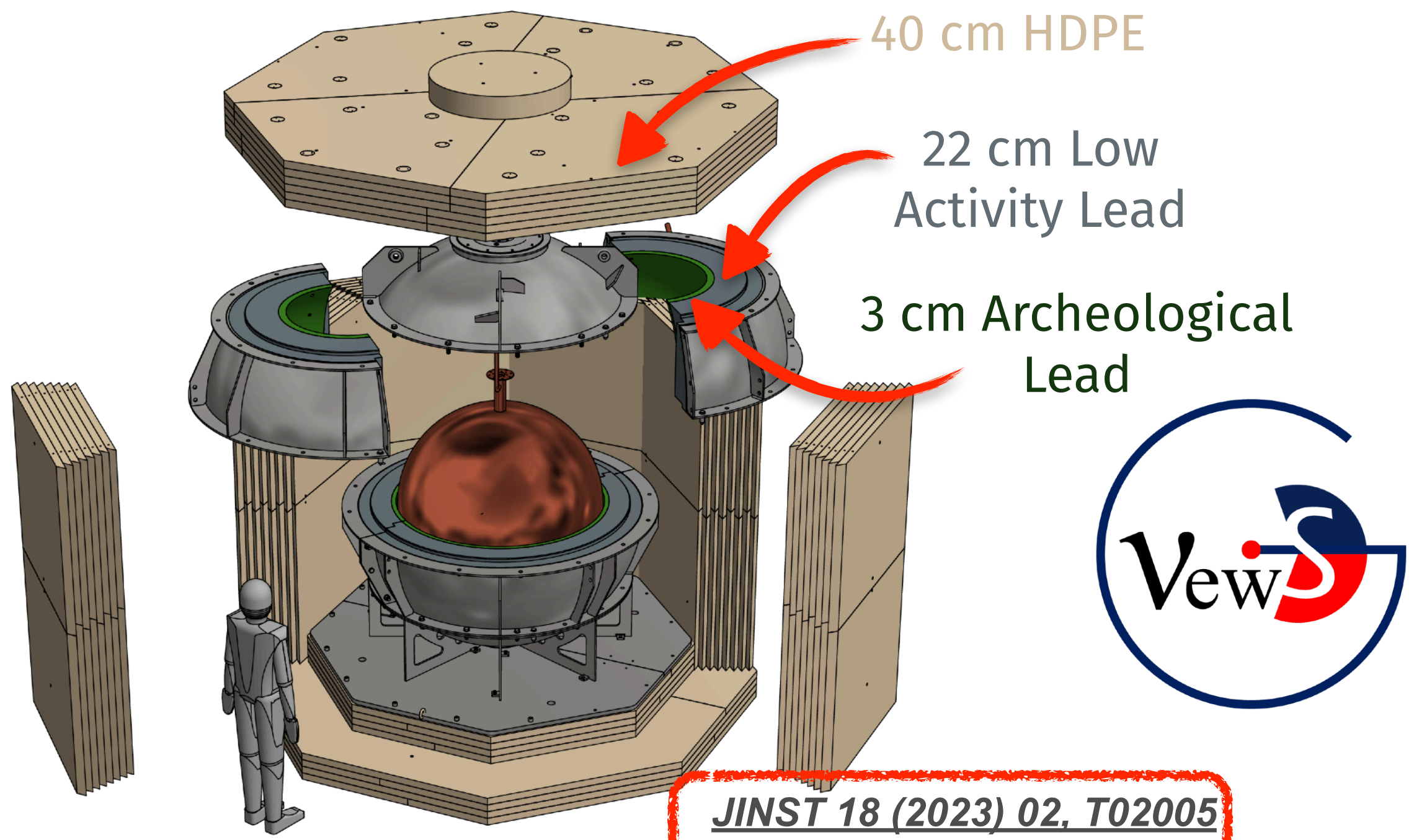


S140 in LSM



SNOGLOBE in SNOLAB

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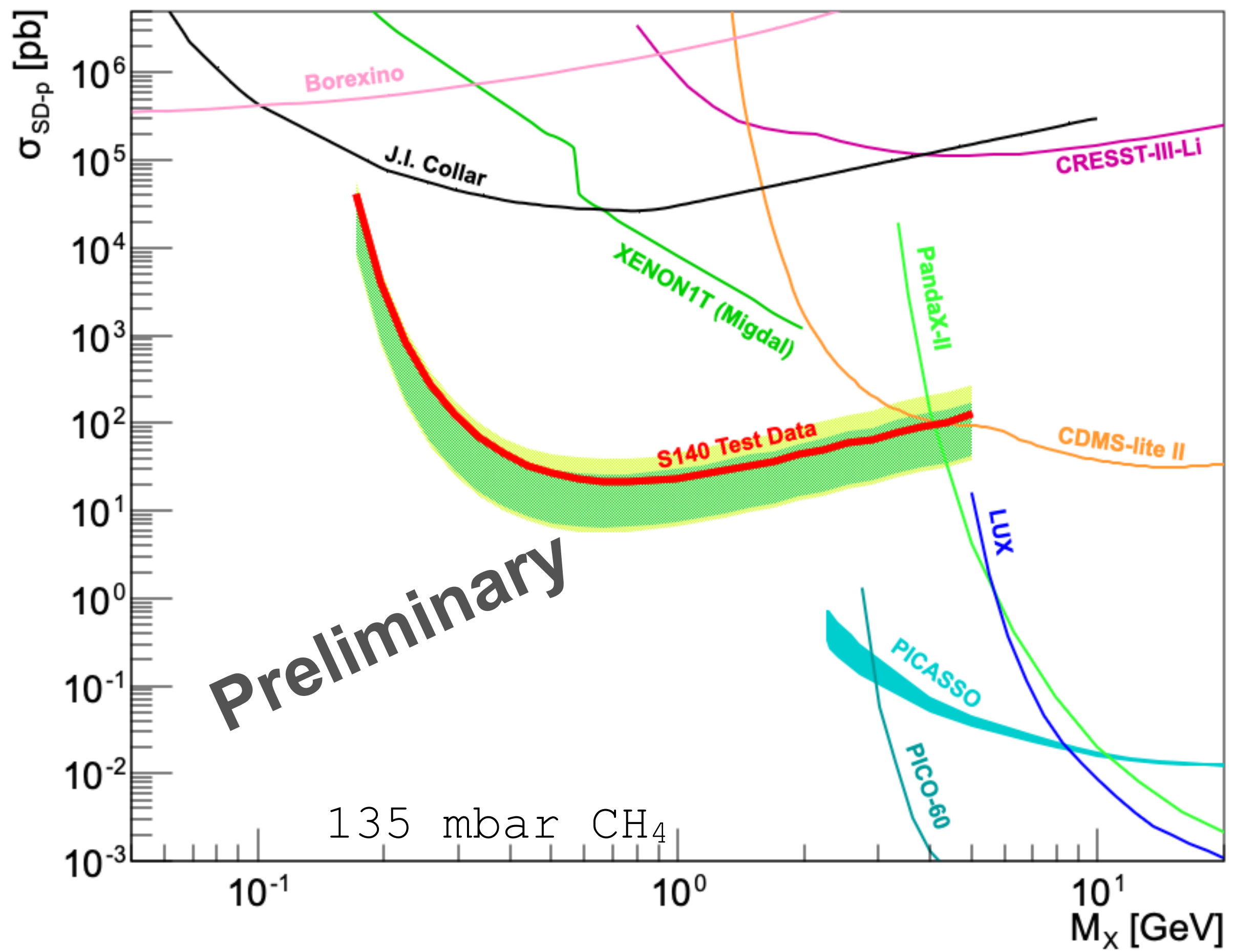


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 - ✓ Commissioning data analysis finalising (CH_4)

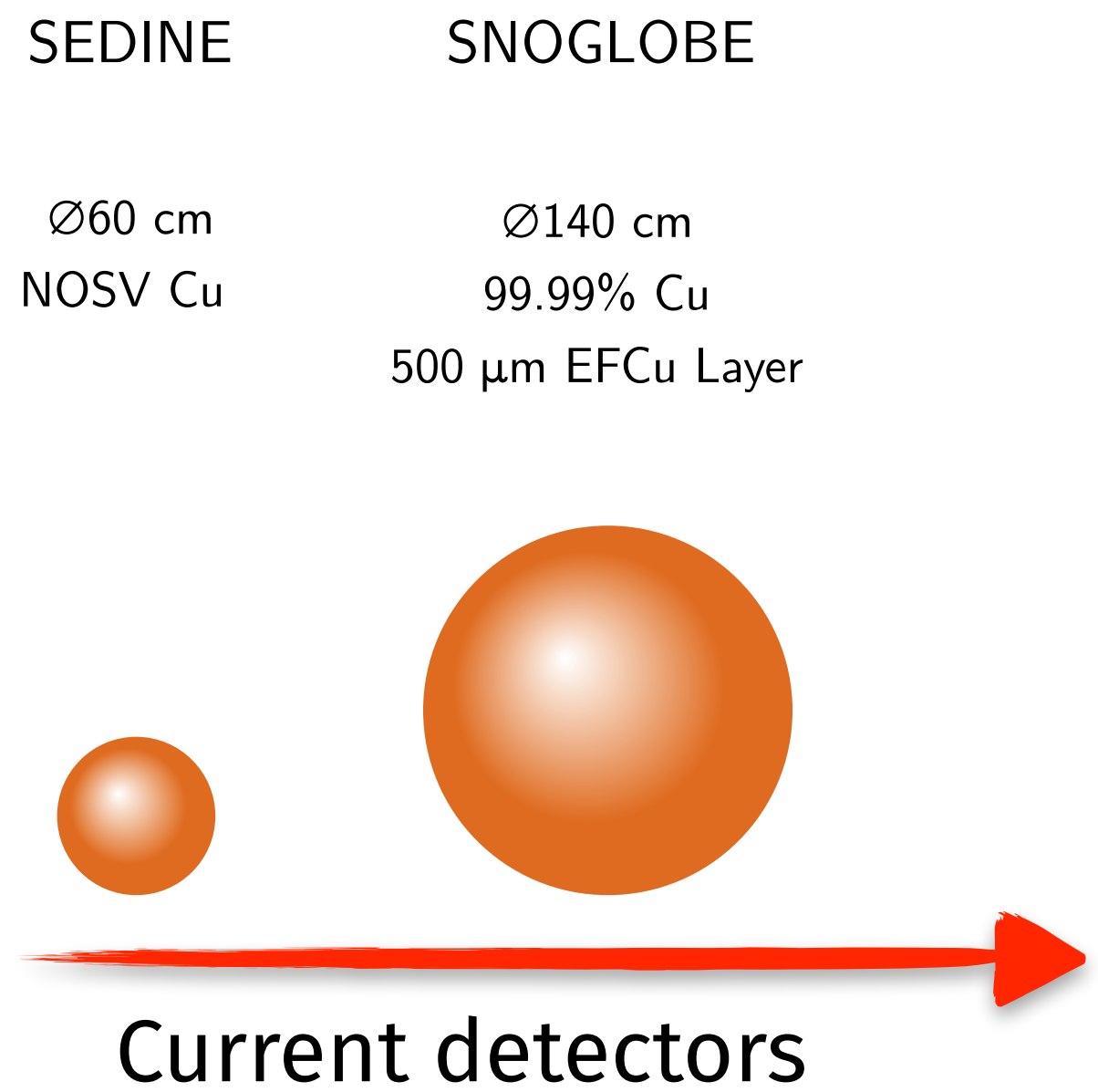
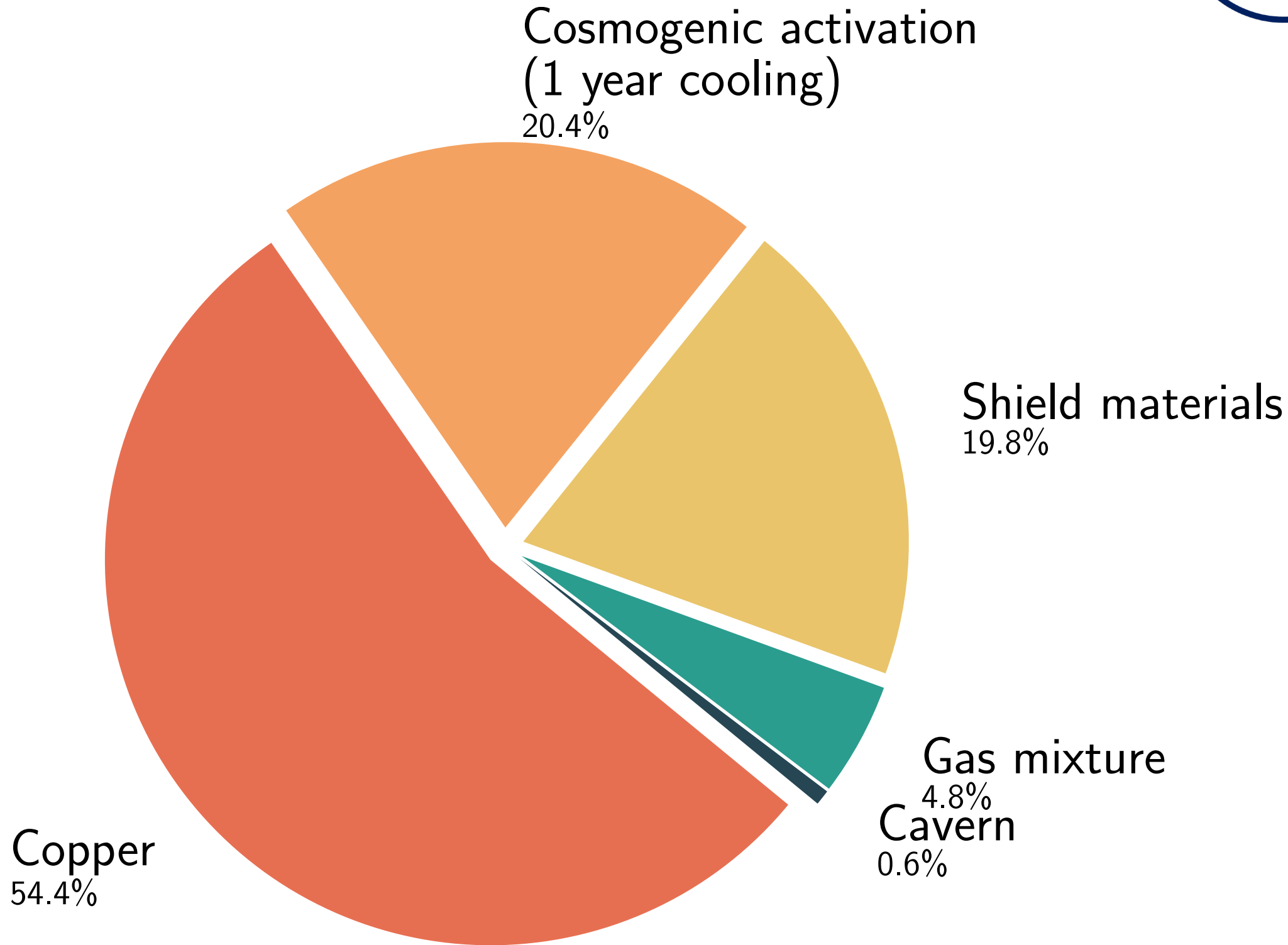
❖ **First physics run in SNOLAB** finished early 2023

- ☐ ~20 kg·days exposure with Ne: CH_4
- ☐ Future physics runs: CH_4 , ...



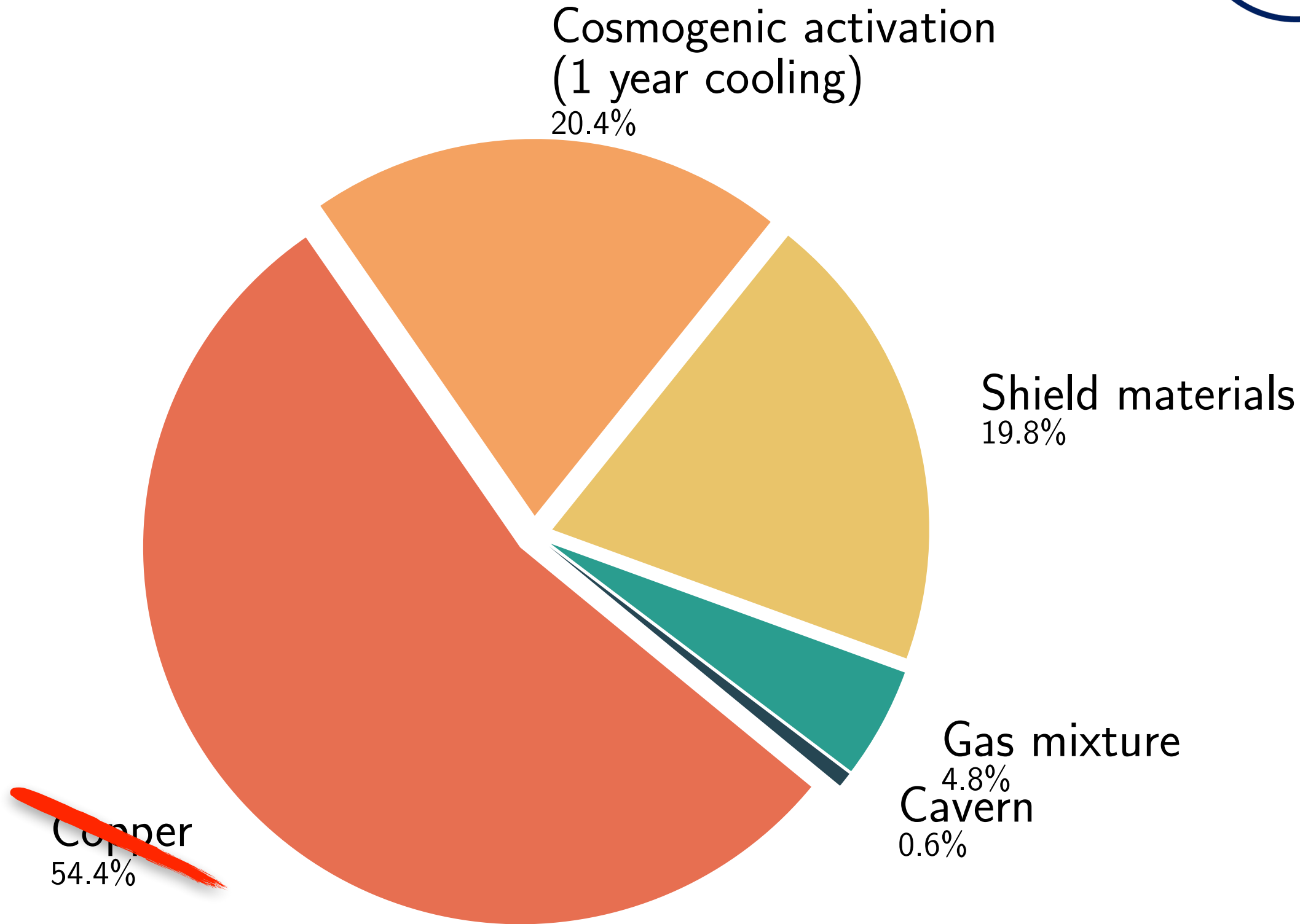
Towards the Neutrino Floor with NEWS-G

Simulated backgrounds in SNOGLOBE



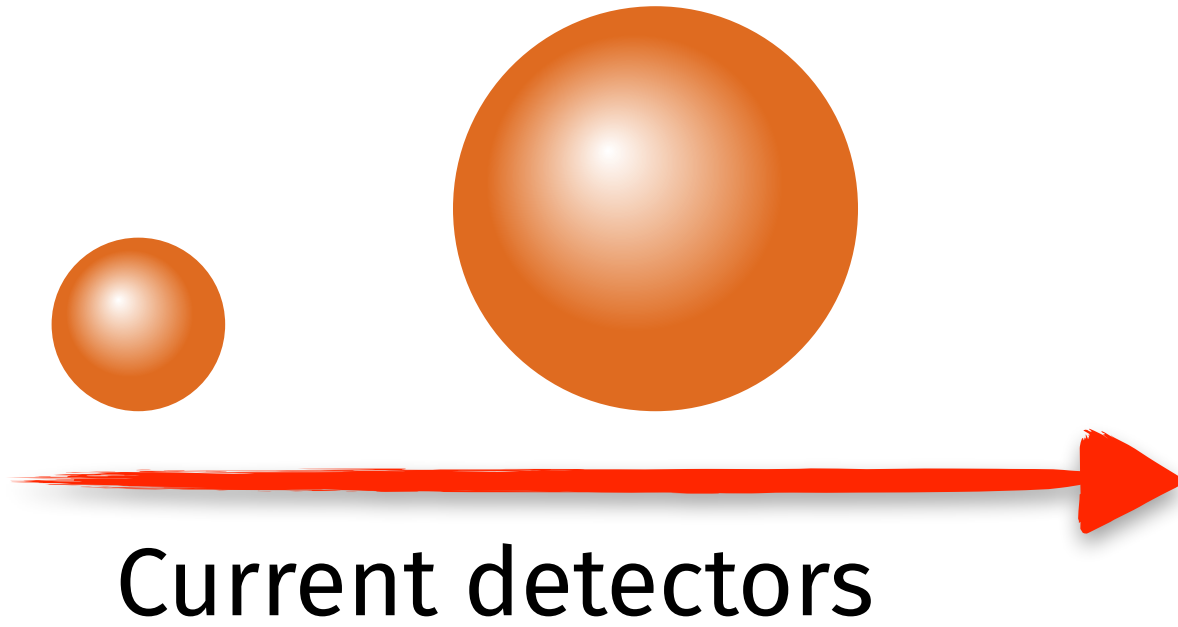
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Electroforming...

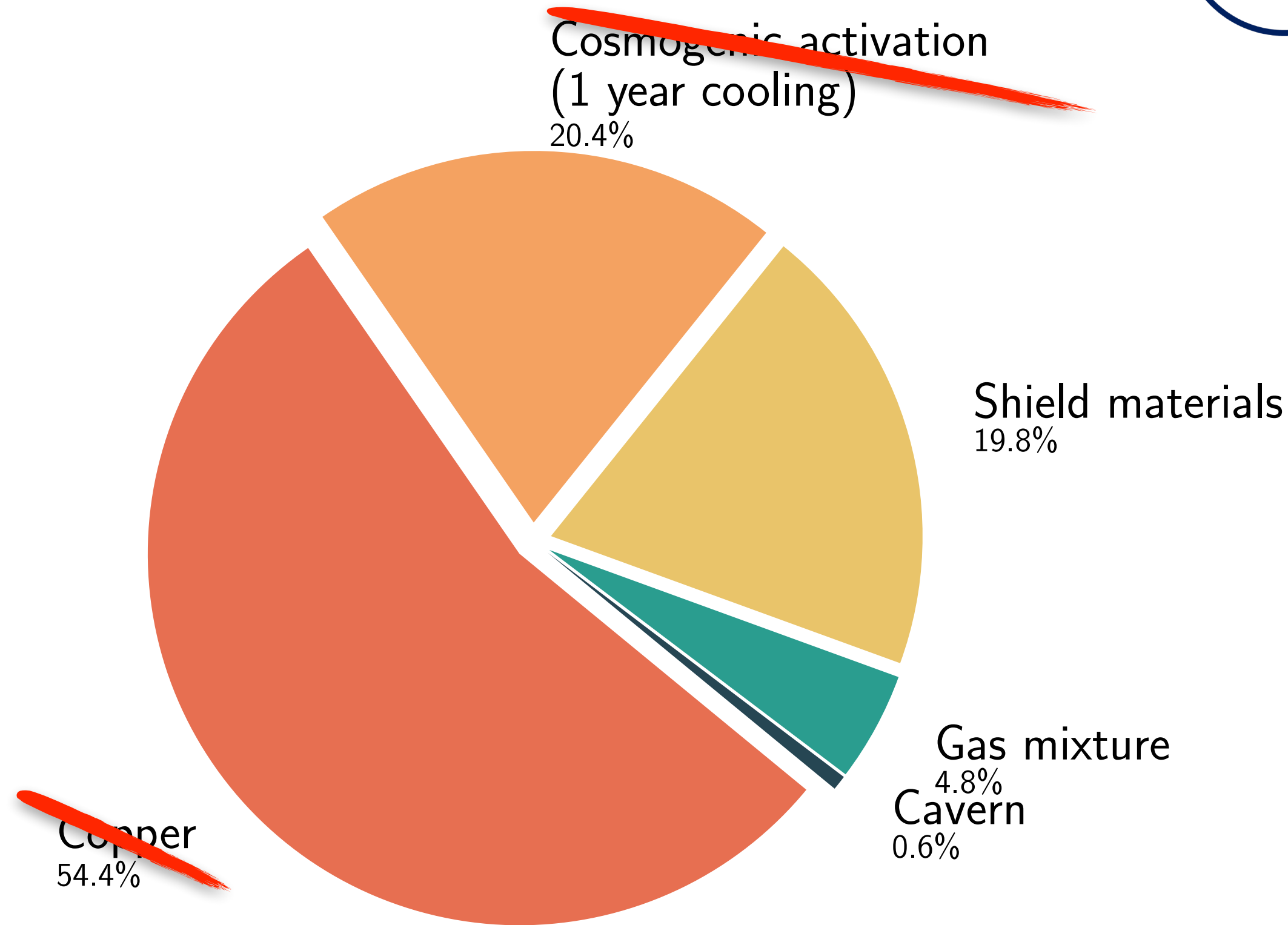
SEDINE	SNOGLOBE
Ø60 cm	Ø140 cm
NOSV Cu	99.99% Cu
	500 µm EFCu Layer



Towards the Neutrino Floor with NEWS-G

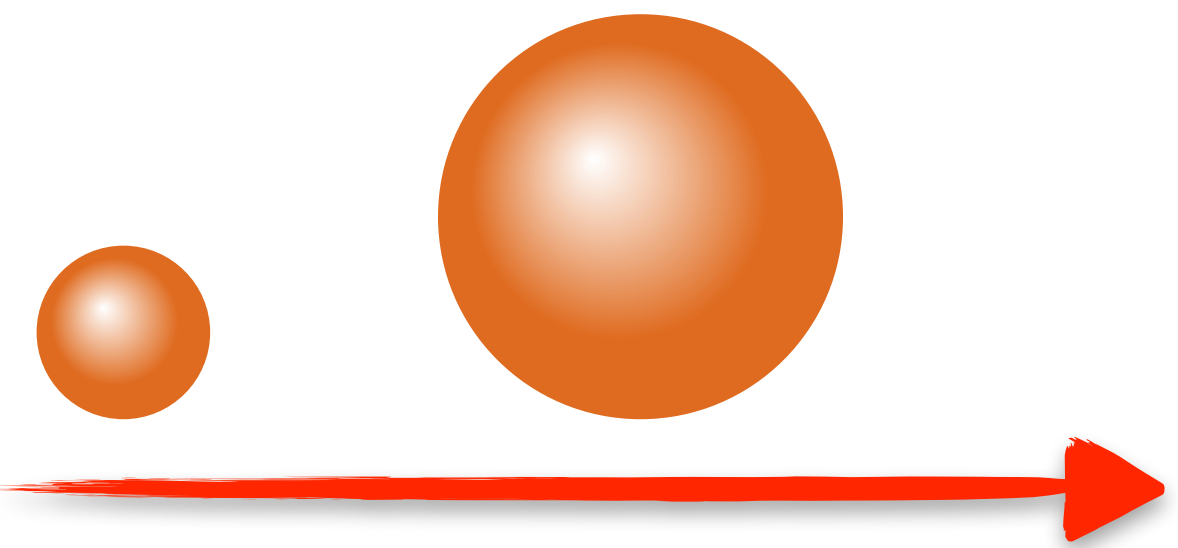
Simulated backgrounds in SNOGLOBE

...underground



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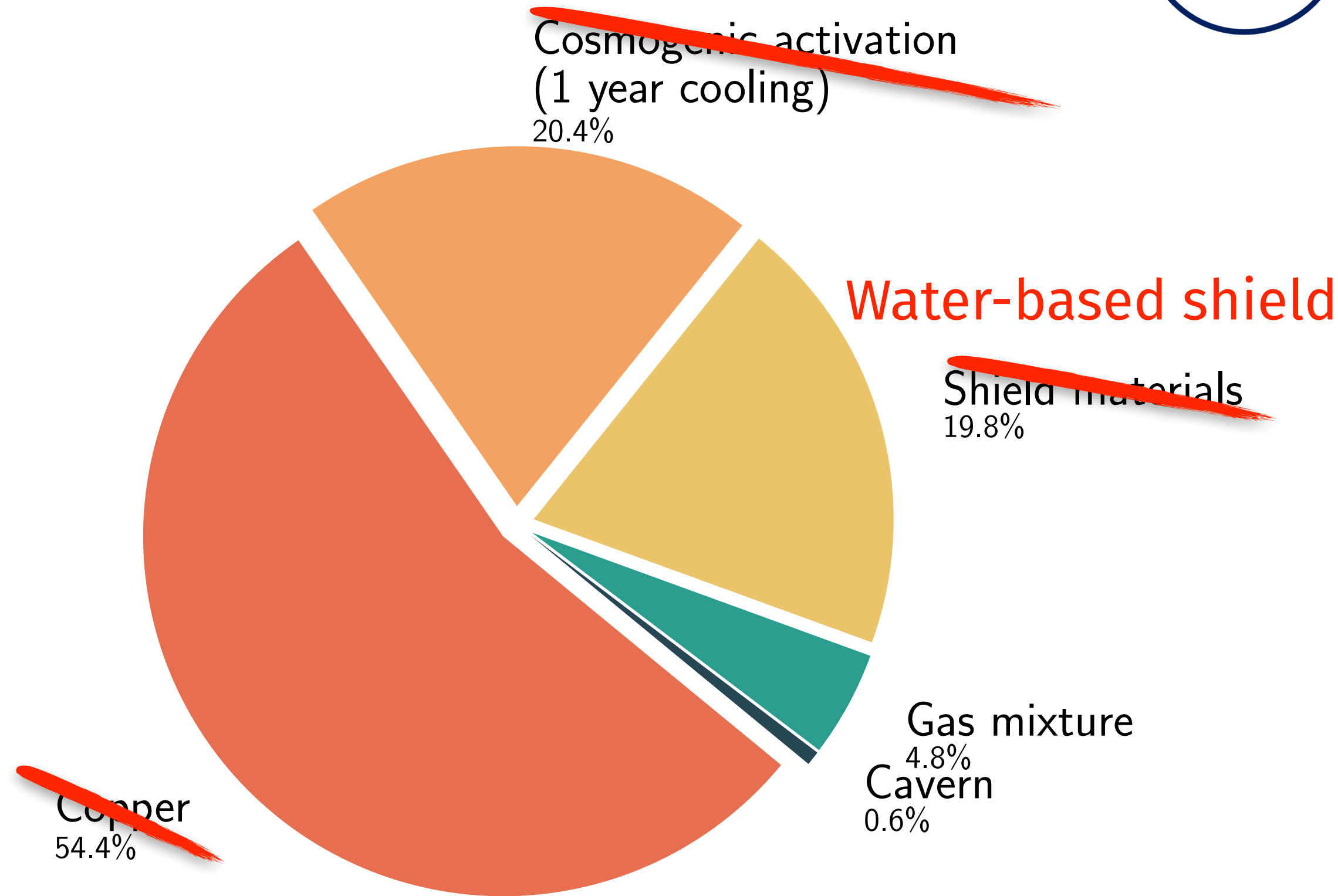


Current detectors

Towards the Neutrino Floor with NEWS-G

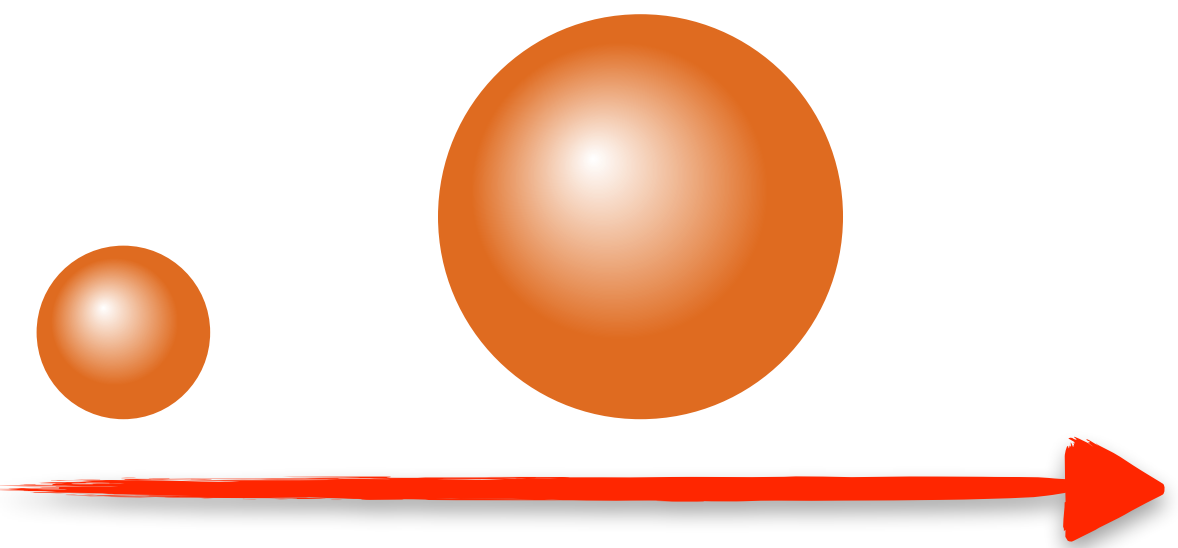
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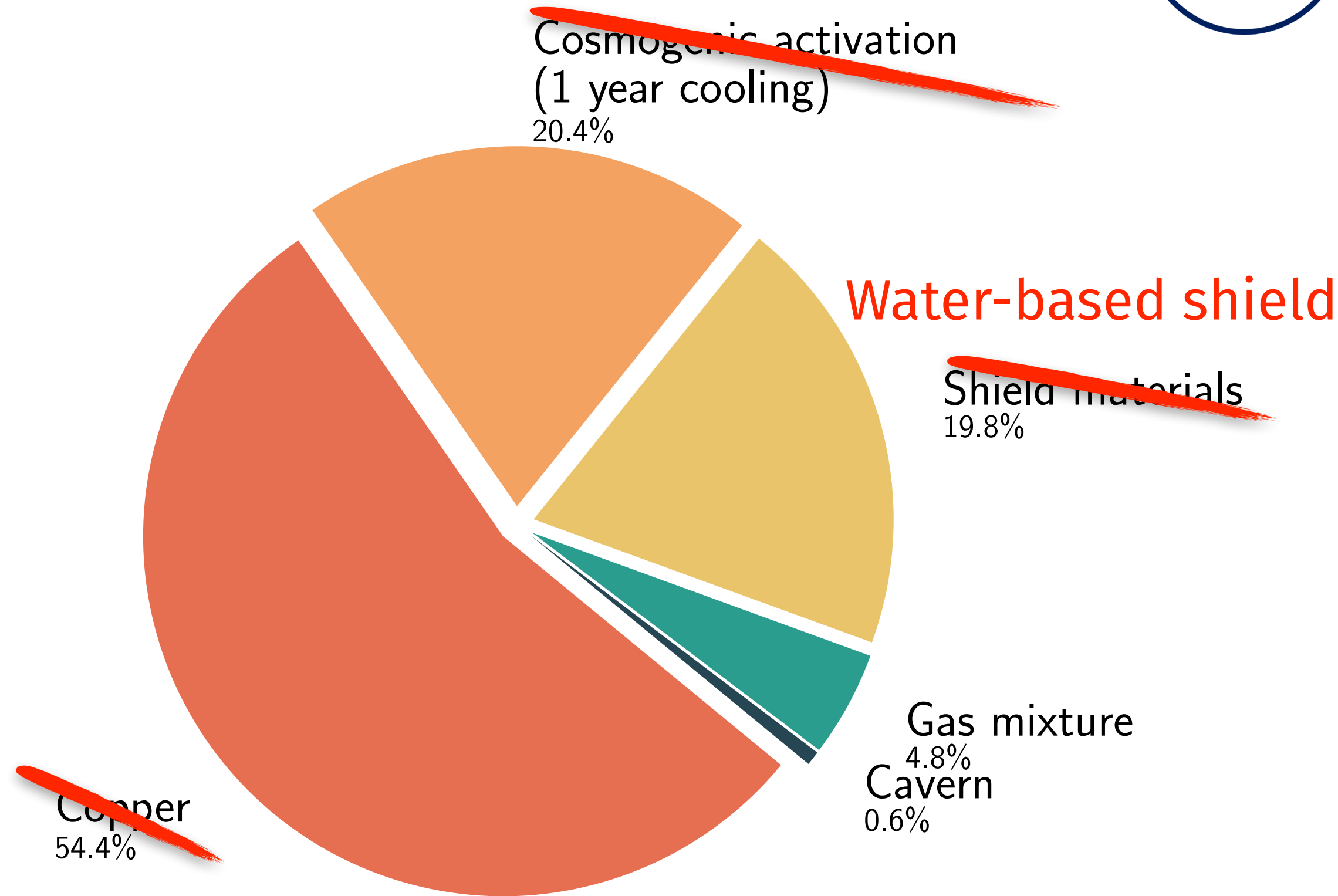


Current detectors

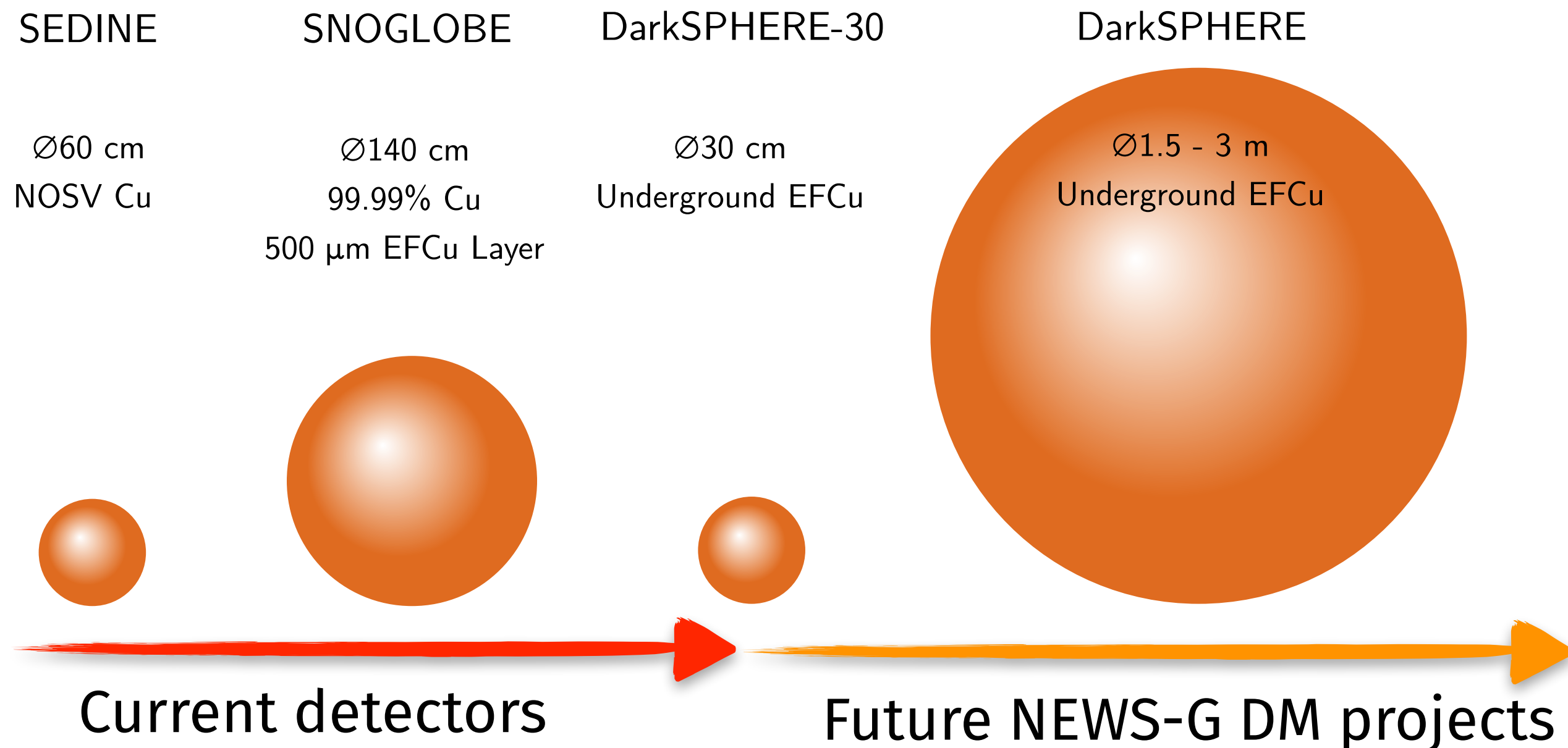
Towards the Neutrino Floor with NEWS-G

Simulated backgrounds in SNOGLOBE

...underground



Electroforming...

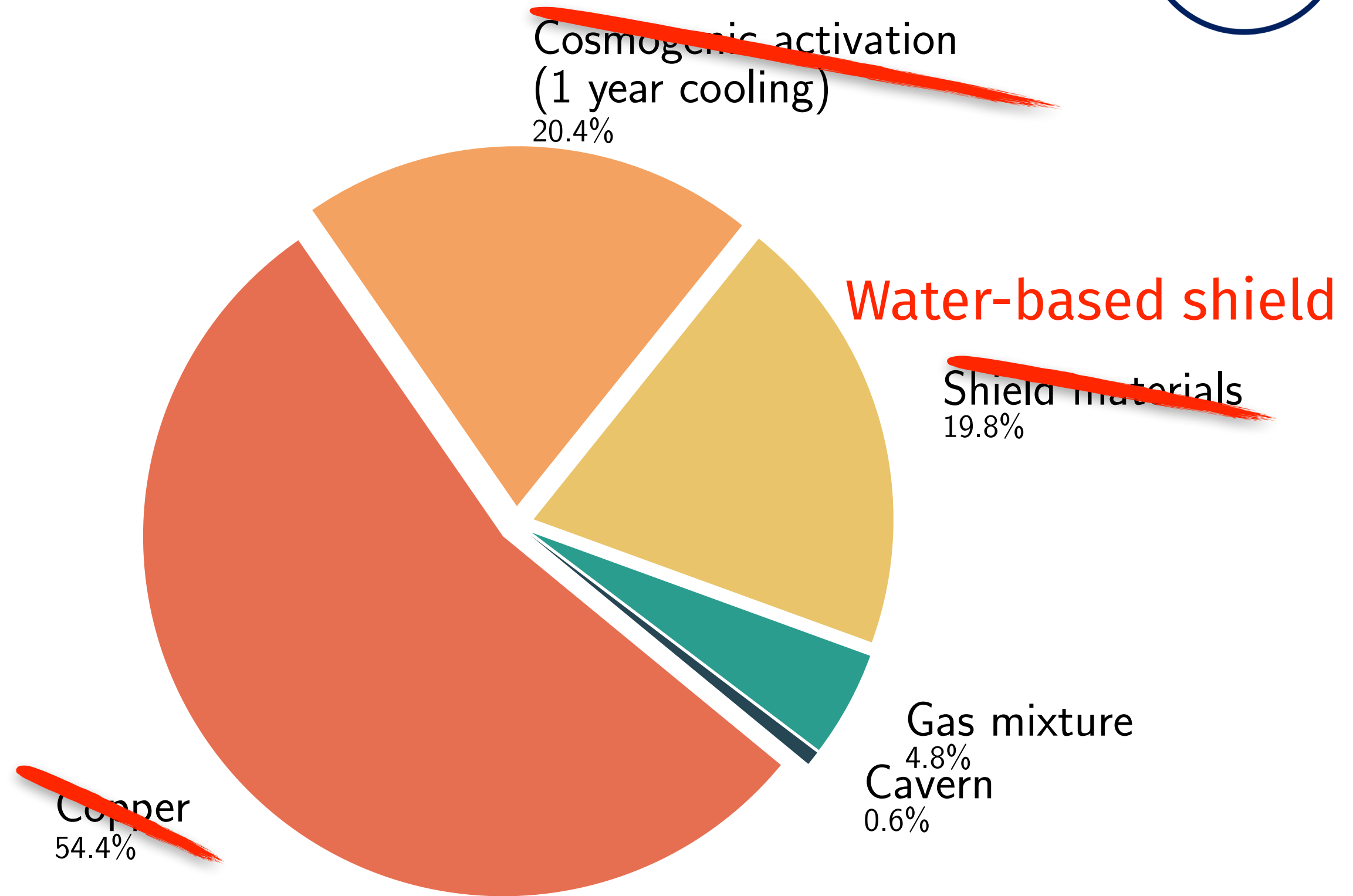


Towards the Neutrino Floor with NEWS-G

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

Simulated backgrounds in SNOGLOBE

...underground



Electroforming...

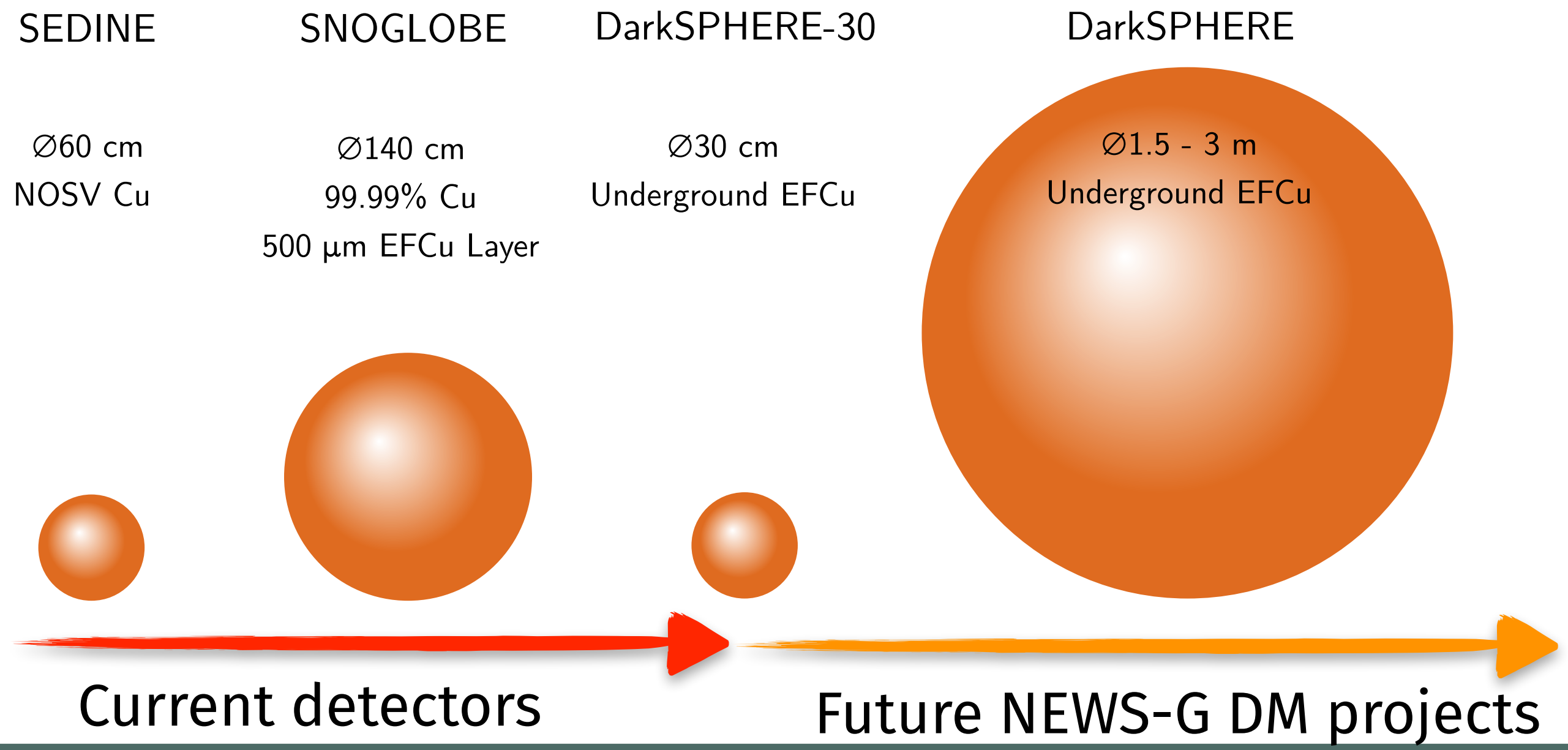
PHYSICAL REVIEW D **108**, 112006 (2023)

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. Manthos⁹ R. D. Martin,³ J. Matthews,⁹ J.-F. Muraz,² T. Neep⁹ K. Nikolopoulos⁹ 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. Ward⁹

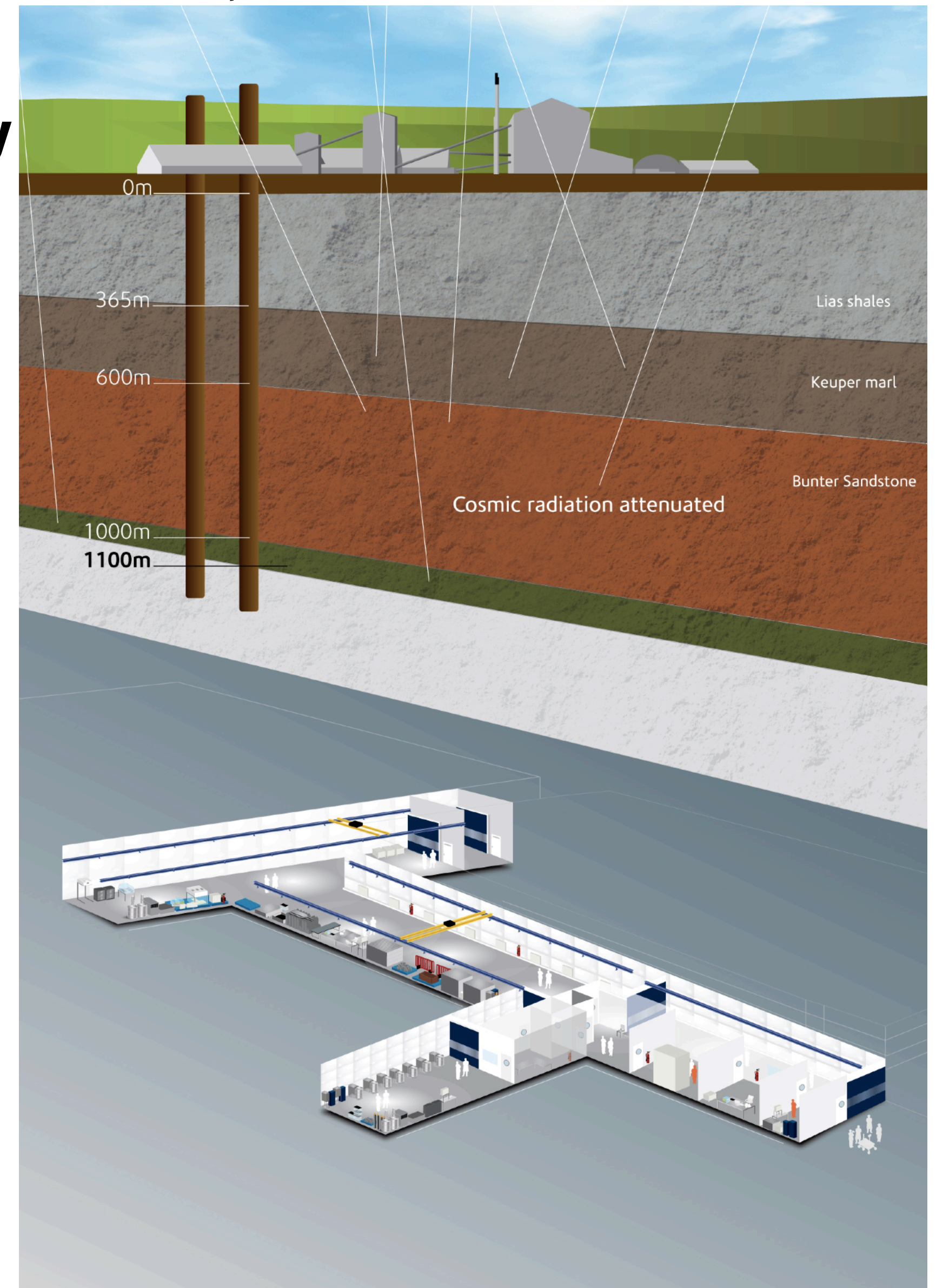
(NEWS-G Collaboration)

E. Banks,¹² L. Hamaide,¹³ C. McCabe¹³ K. Mimasu,¹³ and S. Paling¹²



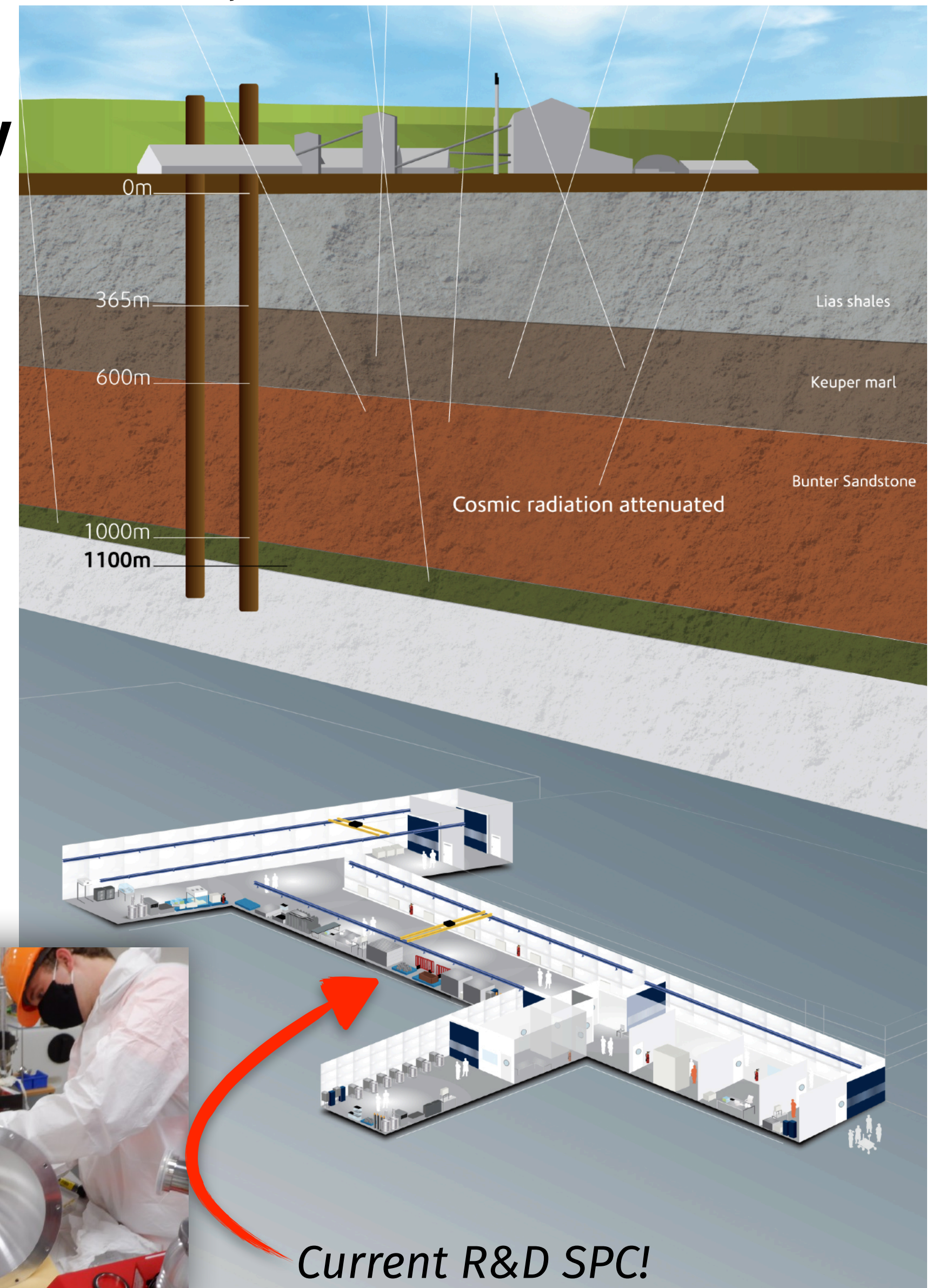
DarkSPHERE in Boulby

- DarkSPHERE will use a modular water-based shield
- Boulby as potential host - **UK's deep-underground science facility**
- A pure water shield is sufficient for background goal of **0.01 event/keV/kg/day** in ROI



DarkSPHERE in Boulby

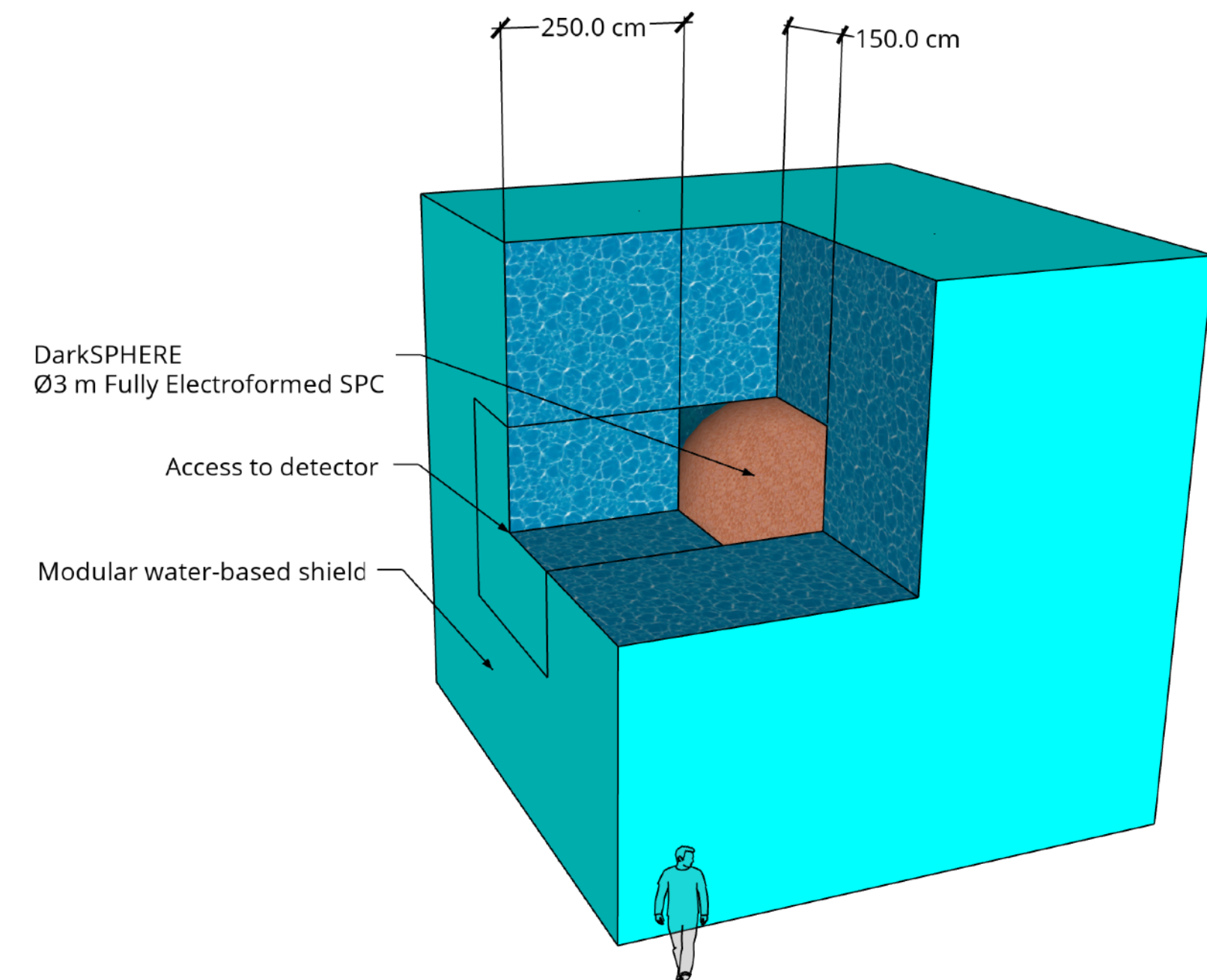
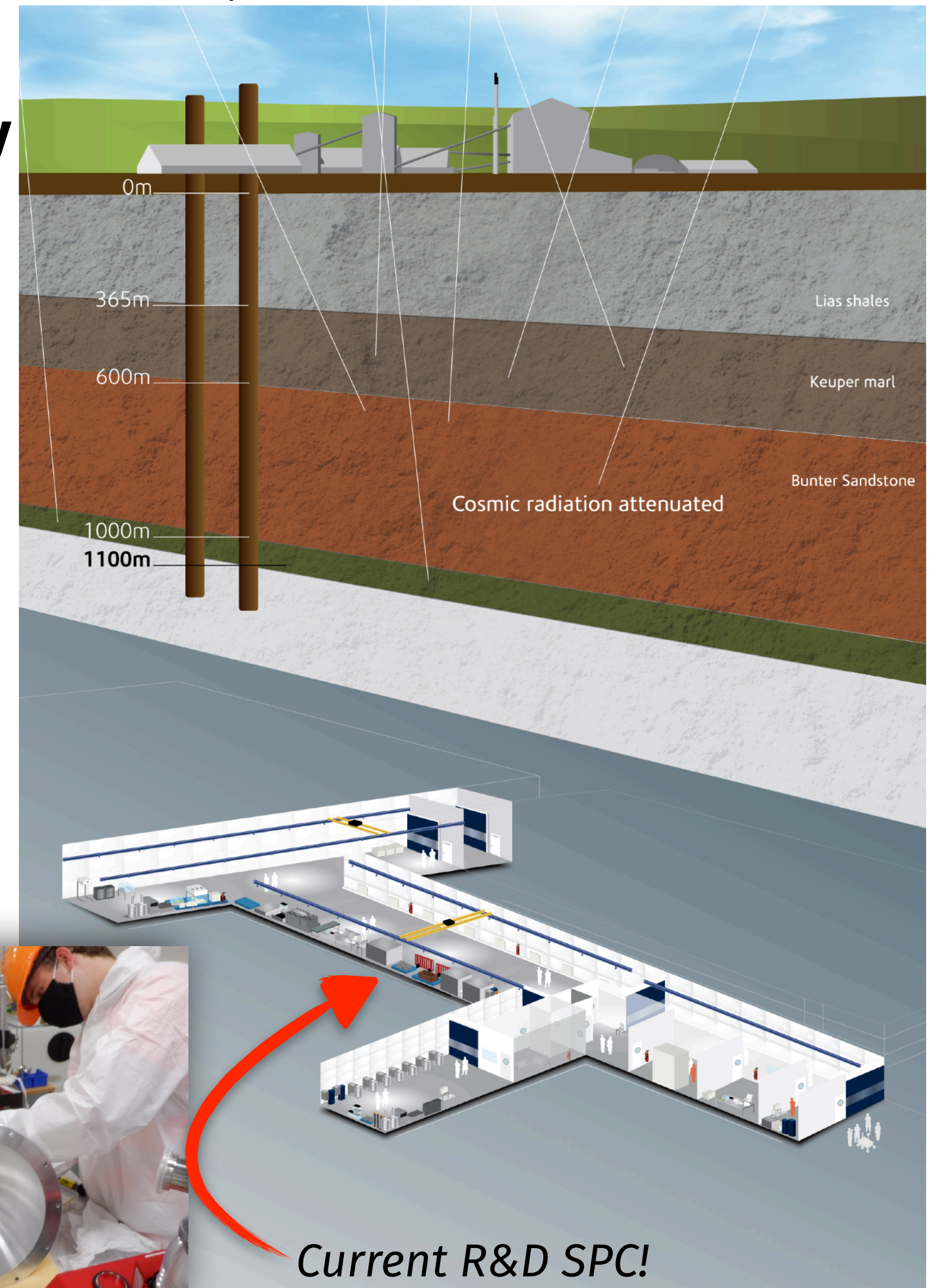
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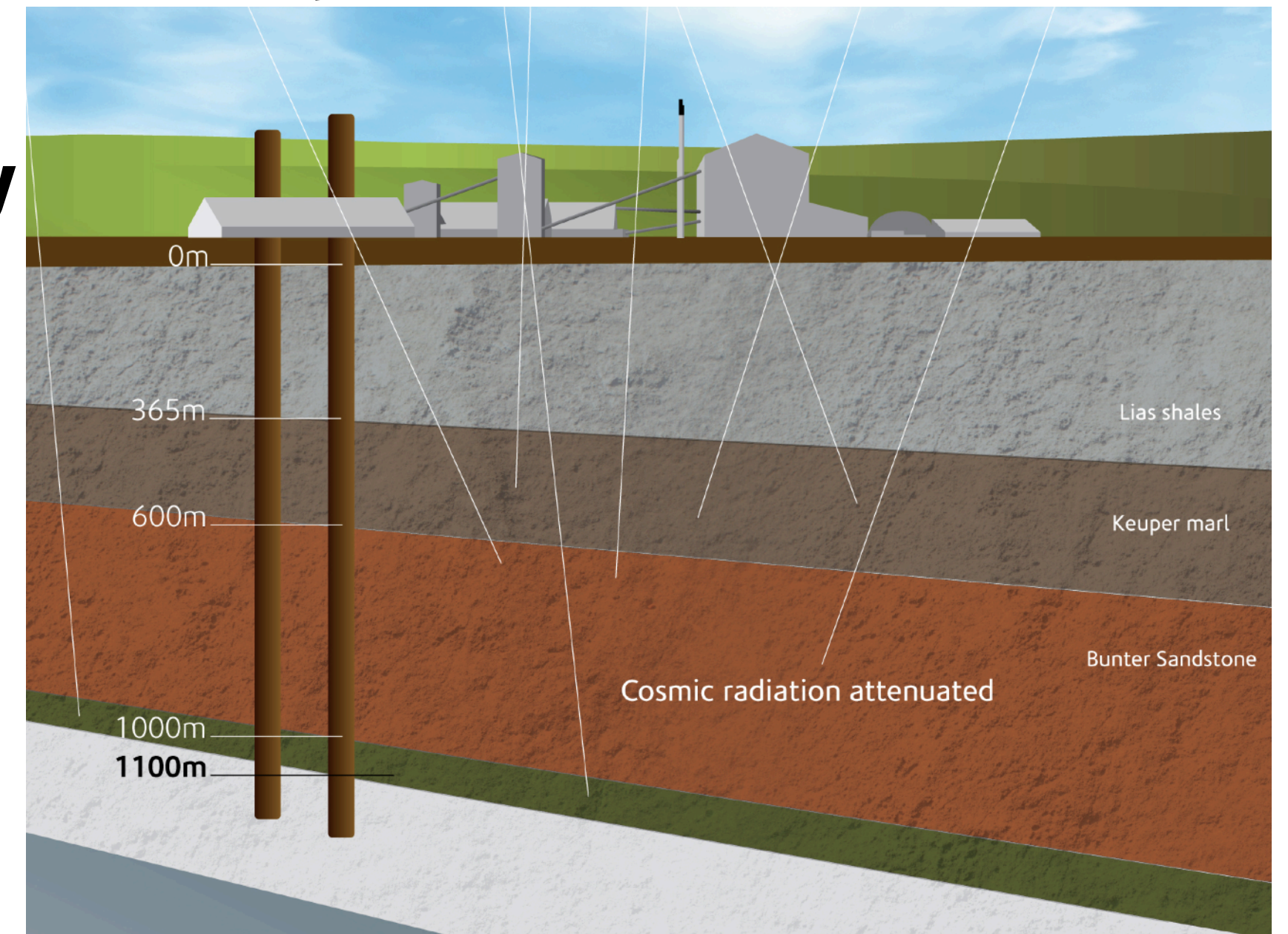
Shielding Configuration	Environmental background rate $\leq 1 \text{ keV}$ [dru]			Muon-induced
	Photon-induced Photon	Neutron-induced Neutron	Neutron-induced Photon	
2.5 m water	4.2×10^{-3} (0.3)	9×10^{-5} (5)	1.3×10^{-4} (0.4)	5×10^{-3} (4)



Current R&D SPC!

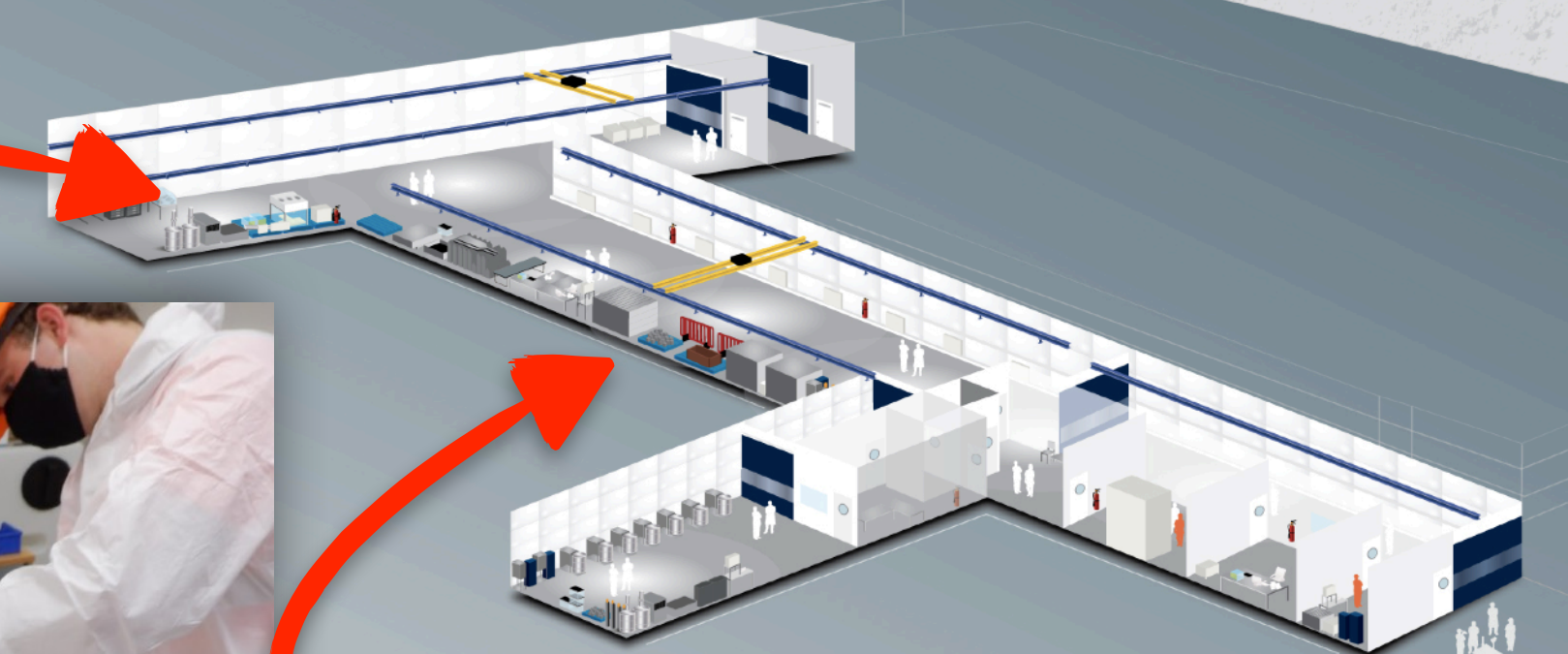
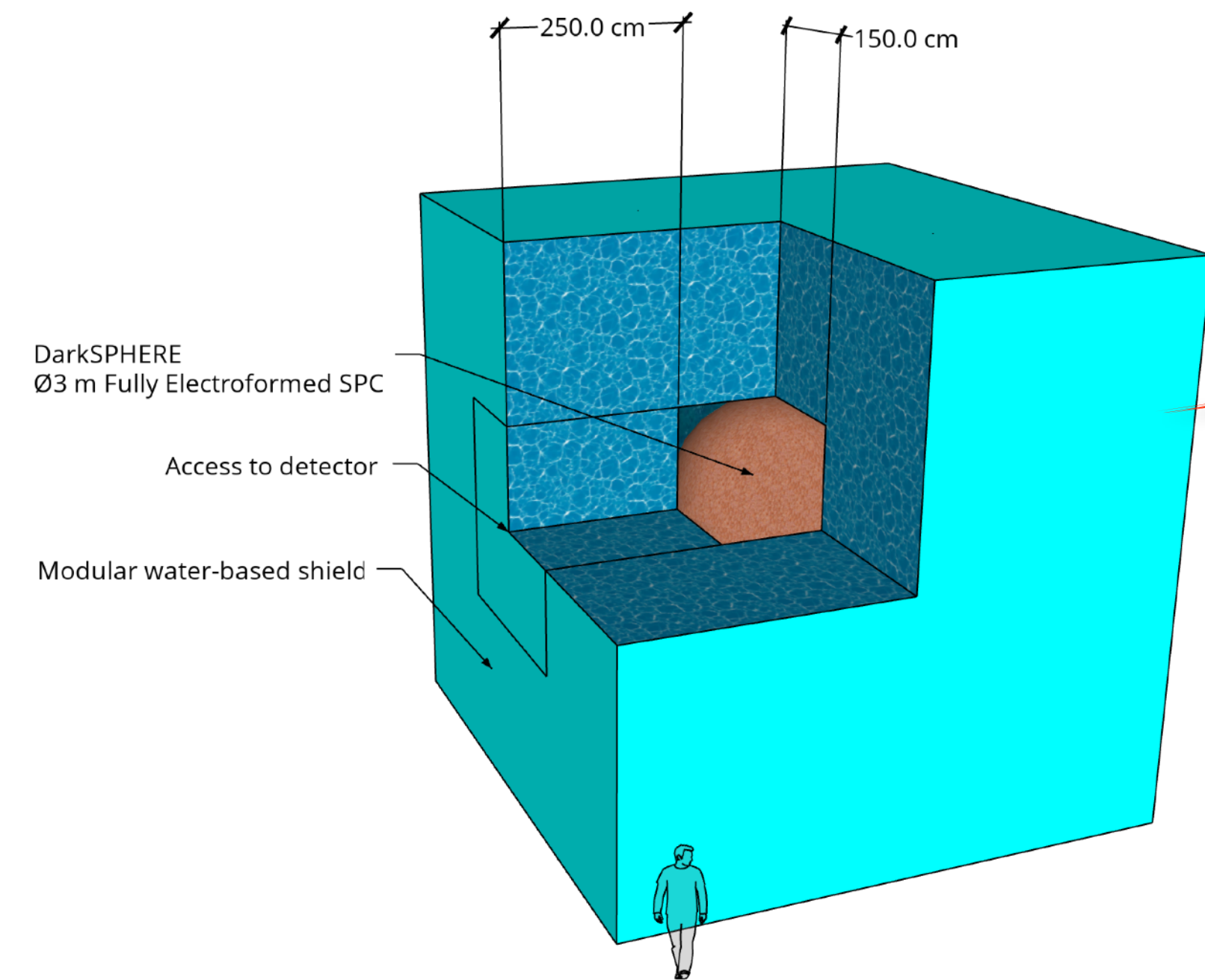
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Conceptual design fits in Large Experiment Cavern



Current R&D SPC!

Boulby EFCu Facility

- STFC funding for an **ultra-pure EFCu facility** underground in Boulby
 - Facility currently under construction
- Complements UK radioassay facilities, ultra-pure manufacturing plans in Boulby, and aspiration to host experiment
 - e.g. electroplating for Rn emanation reduction in XLZD

Example electroforming bath
at Pacific Northwest National Laboratory

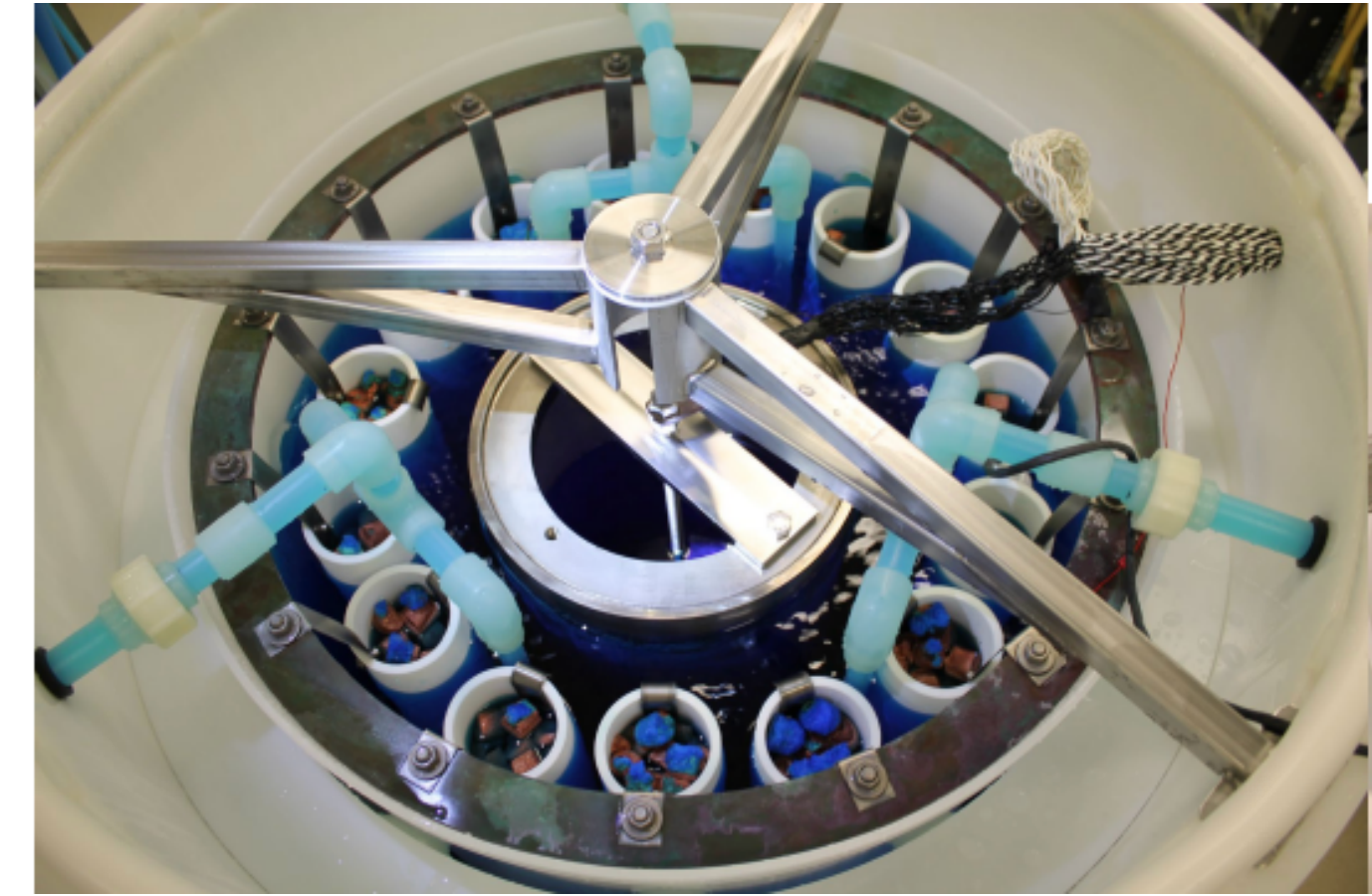


Image credit: E W Hoppe, PNNL

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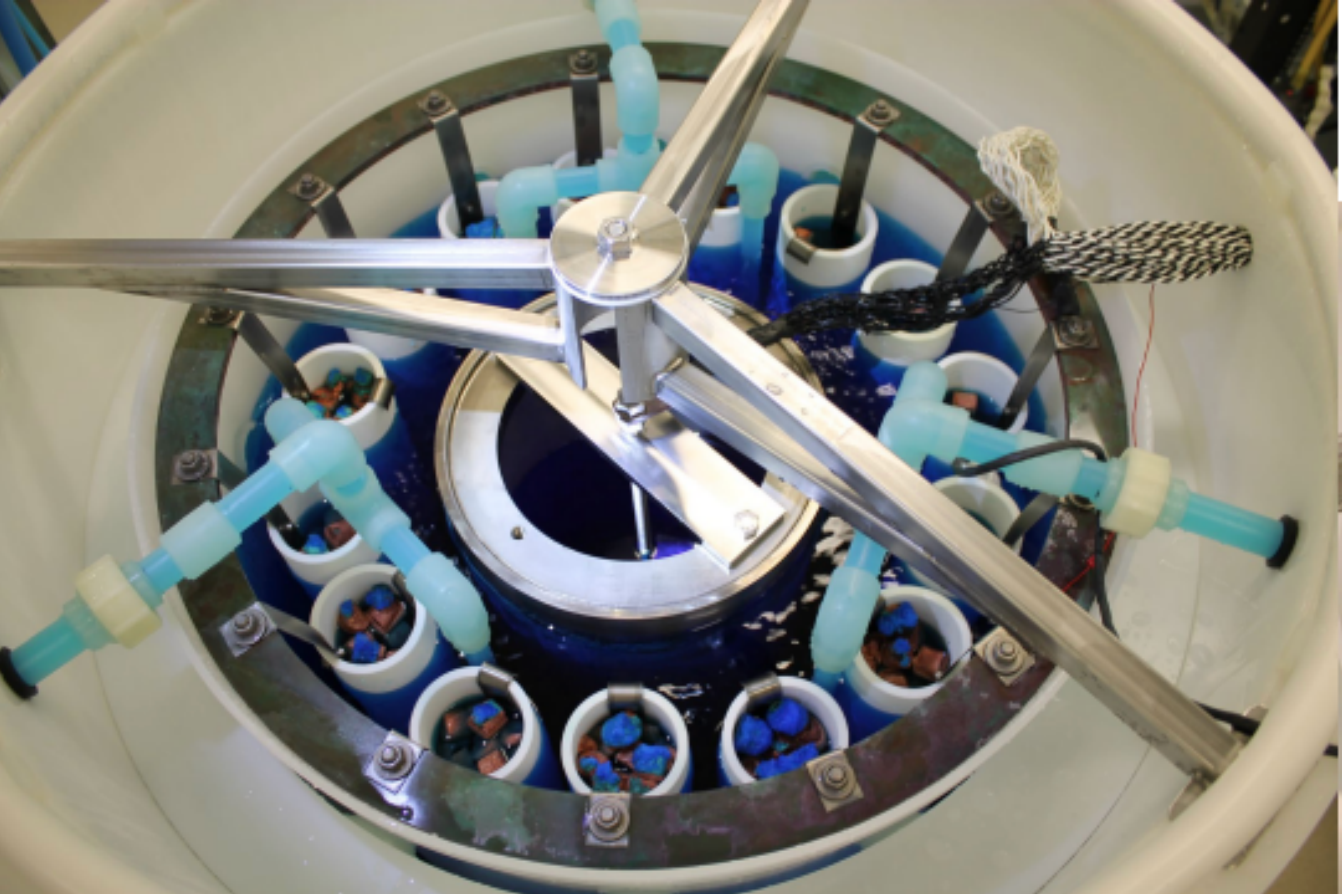
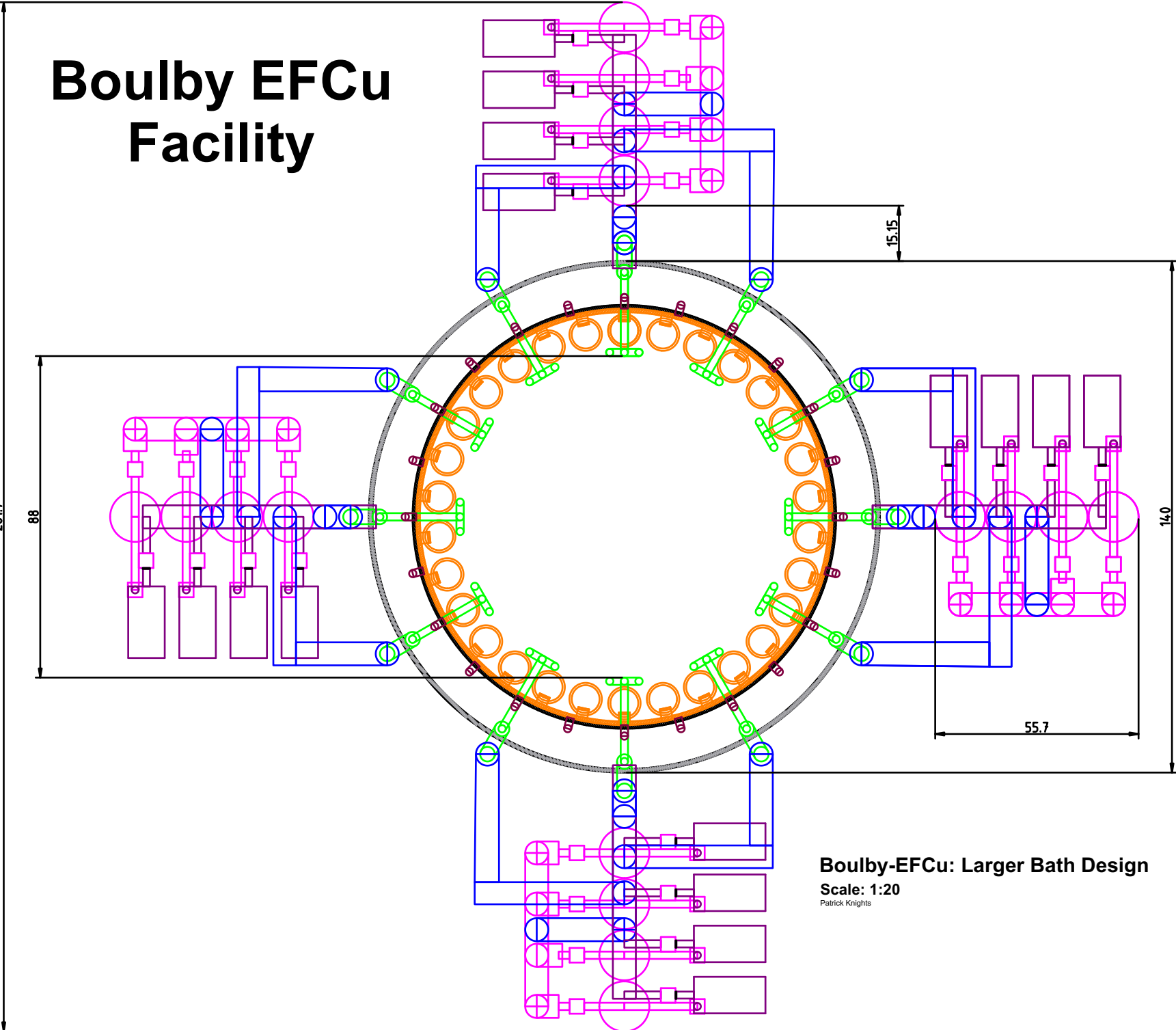


Image credit: E W Hoppe, PNNL



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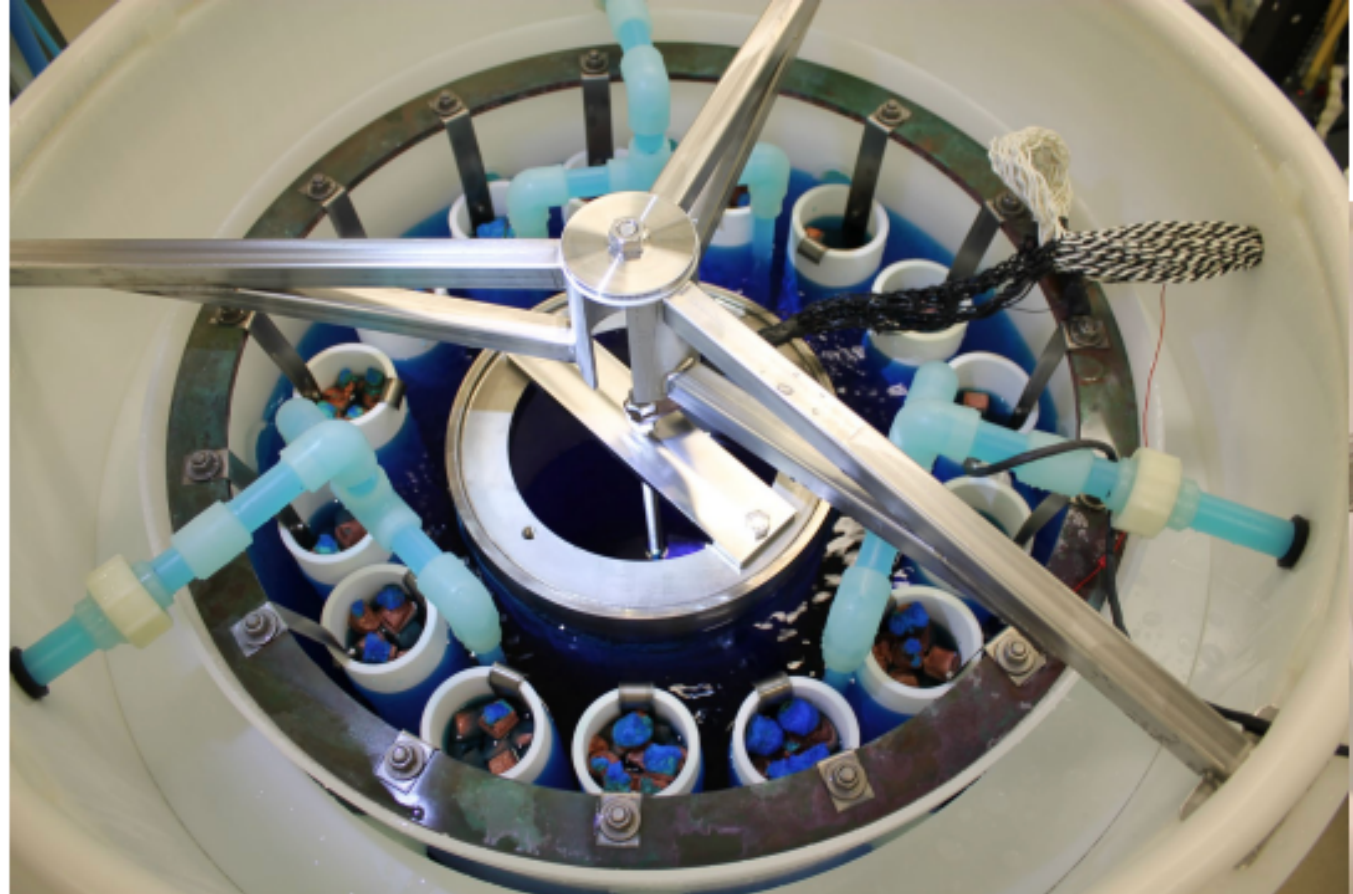
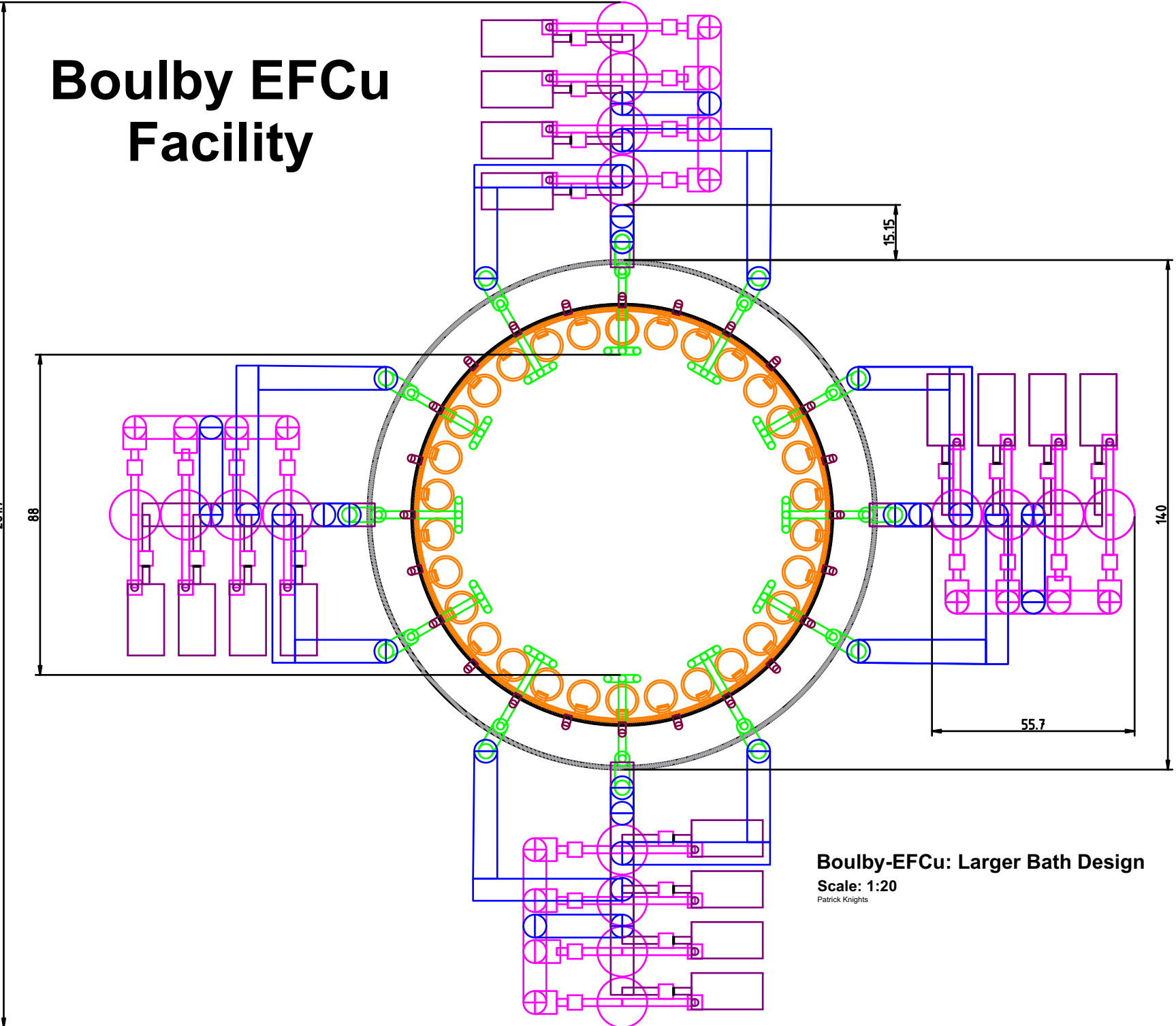


Image credit: E W Hoppe, PNNL



First EFCu test in Boulby



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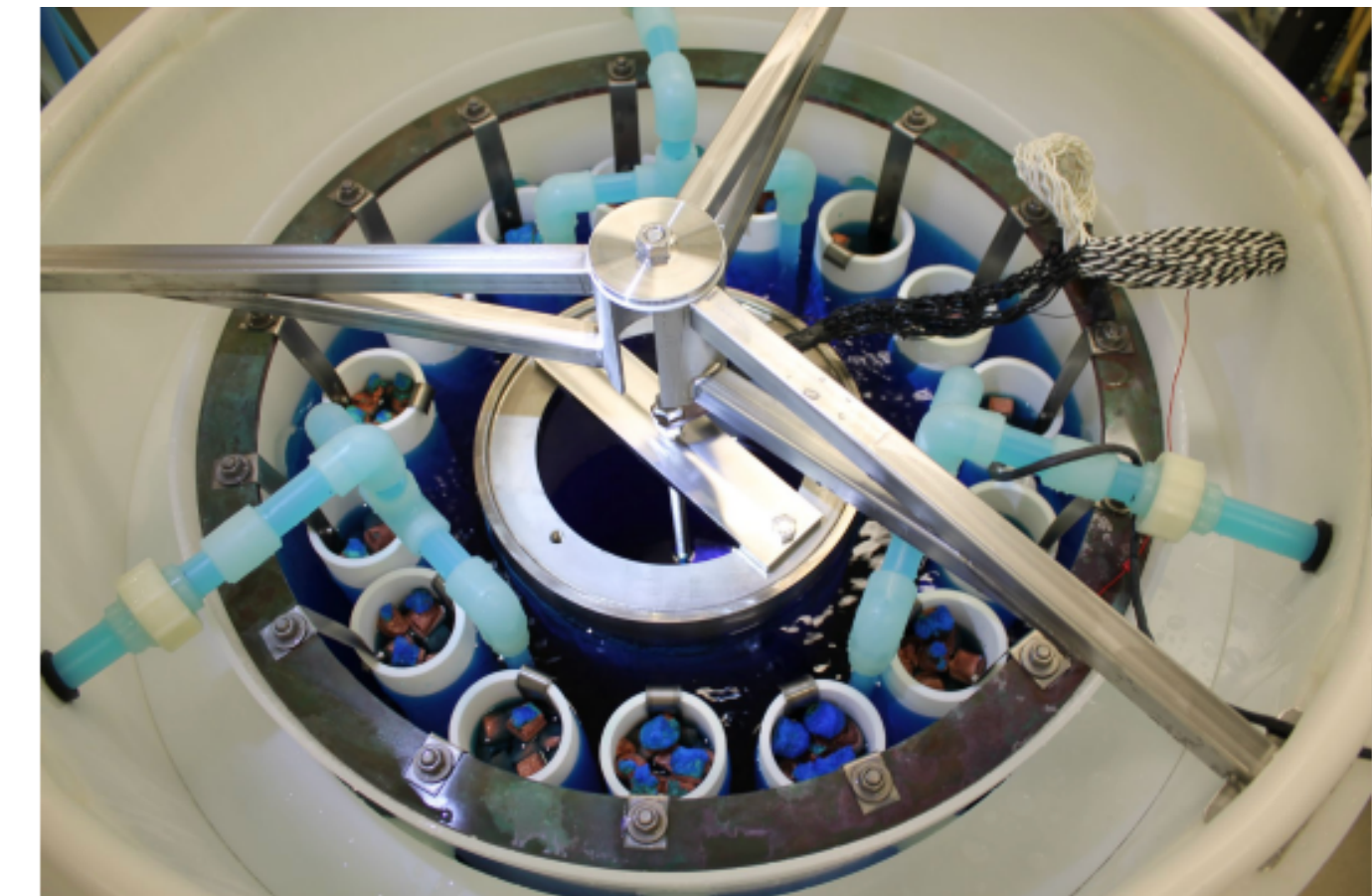
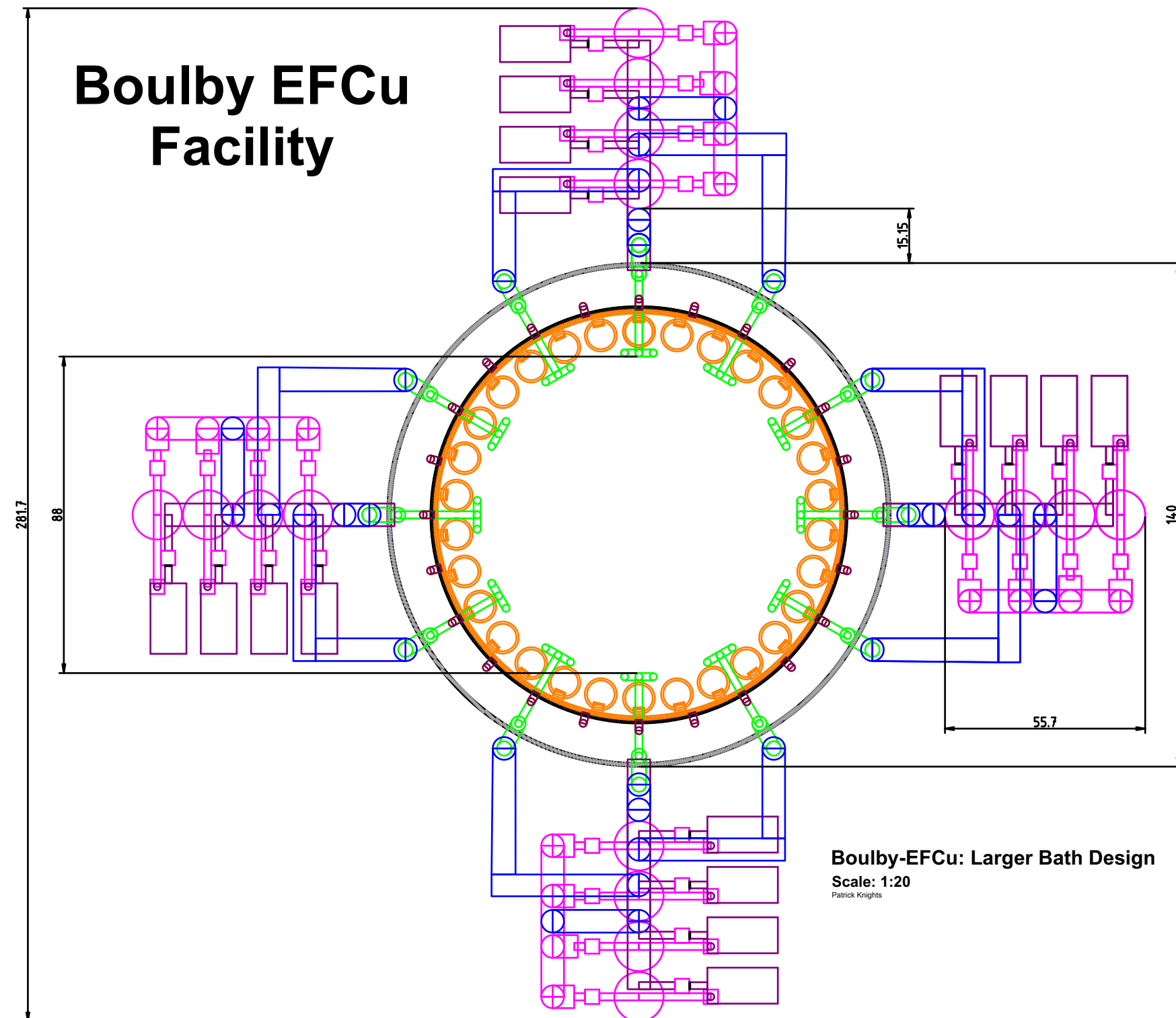


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Construction of bath underway

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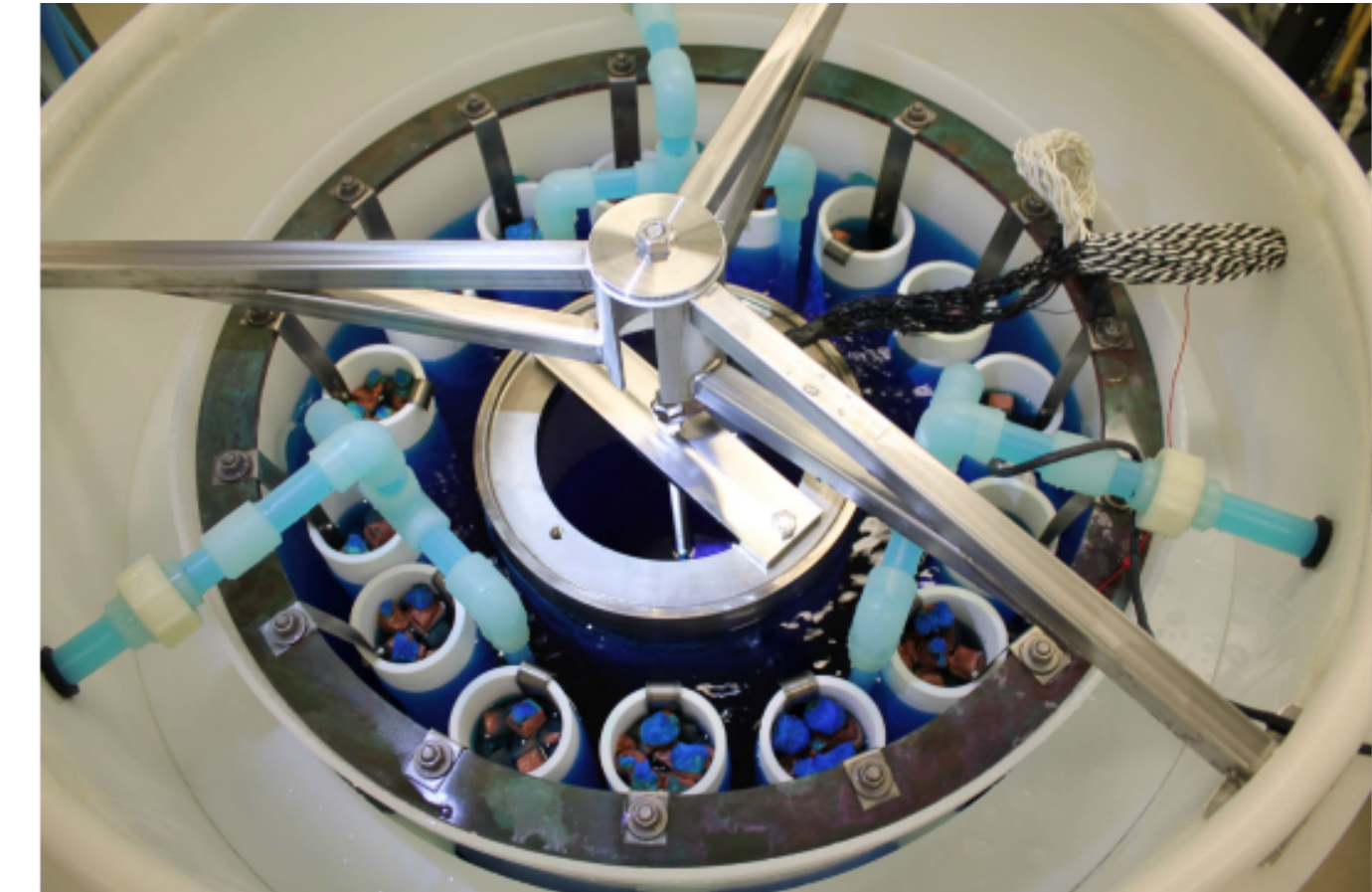
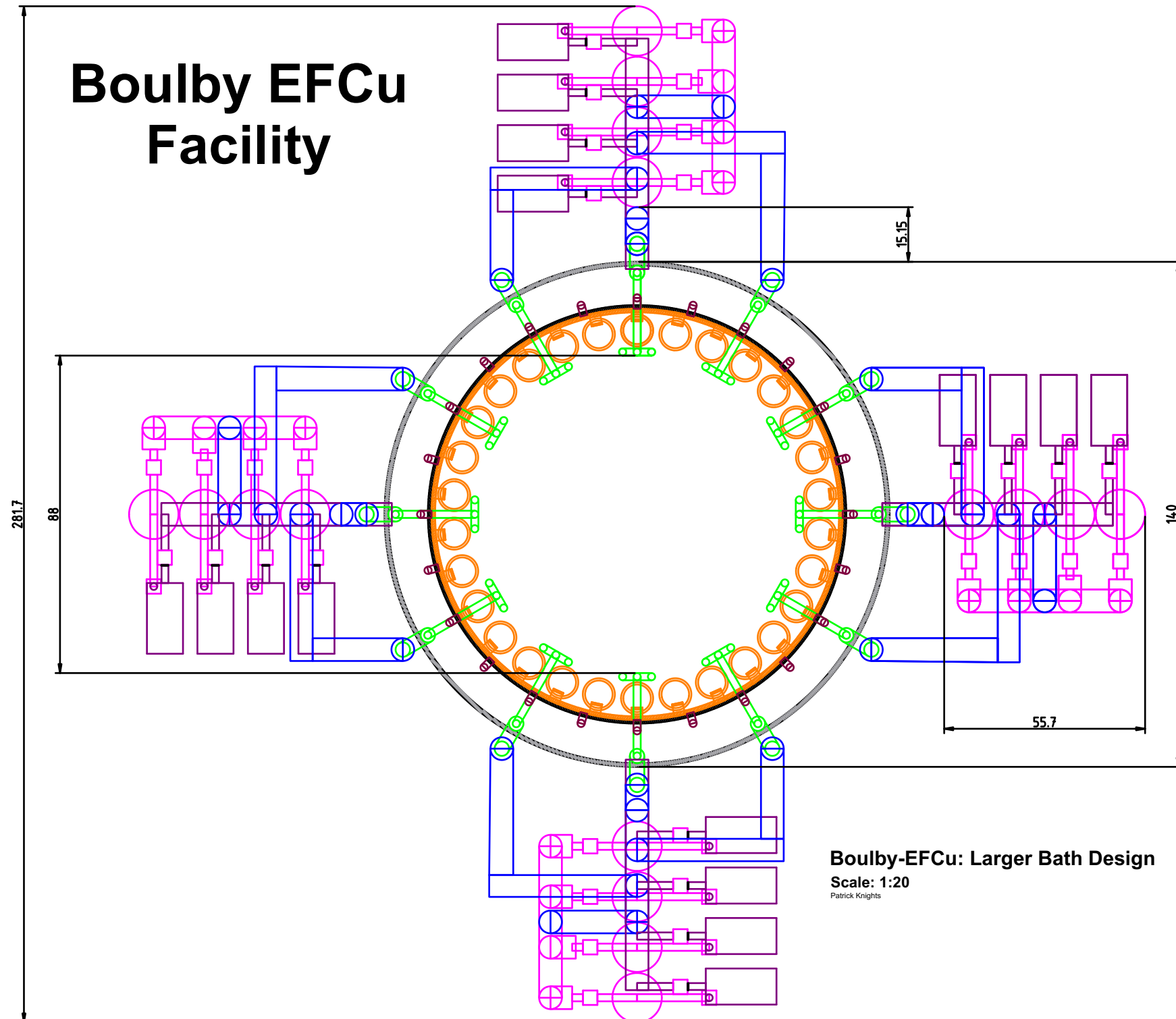


Image credit: E W Hoppe, PNNL



Ø30cm SPC with world-leading physics potential to begin construction this year!

First EFCu test in Boulby

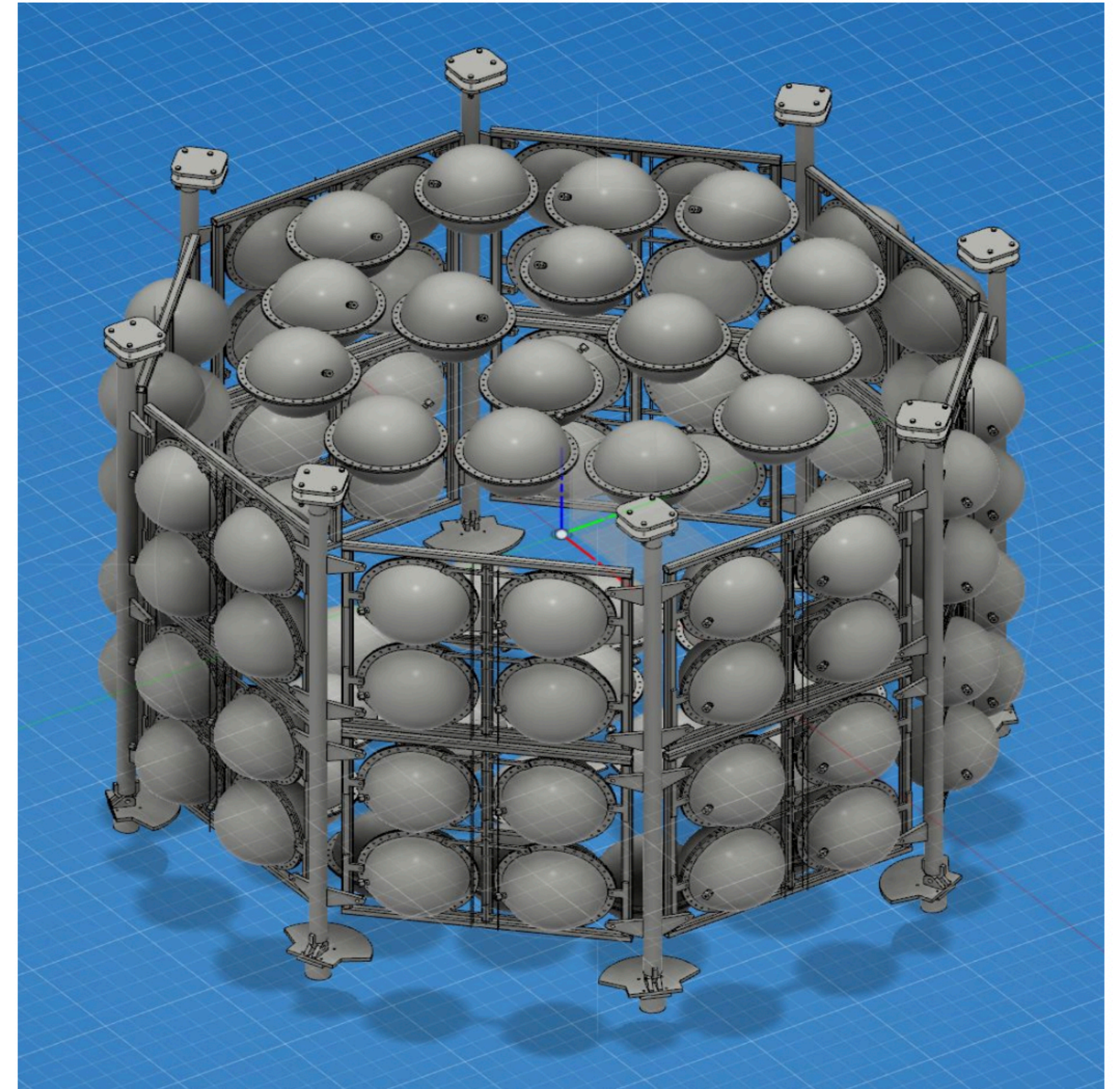
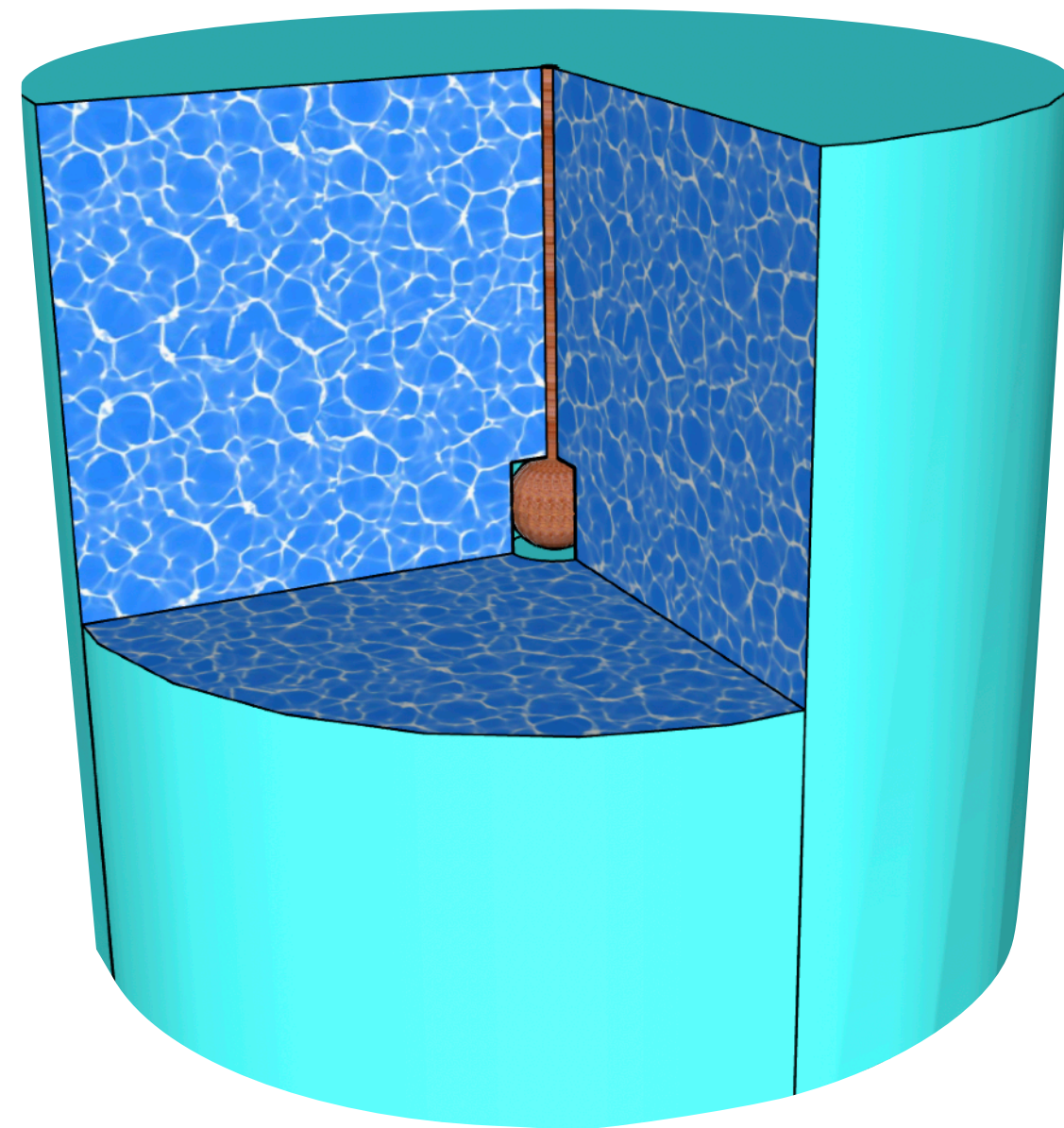


Construction of bath underway

Exploring Synergies with BUTTON

- **BUTTON** - technology test bed for ν detection technologies
- **BUTTON-30 under construction** in Boulby
 - ➔ ~30 tonne first stage instrumented by ~100 10" PMTs
 - ➔ Fill media: water and water-based liquid scintillators (+Gd doping)
- Exploring synergies as **active veto** for DarkSPHERE

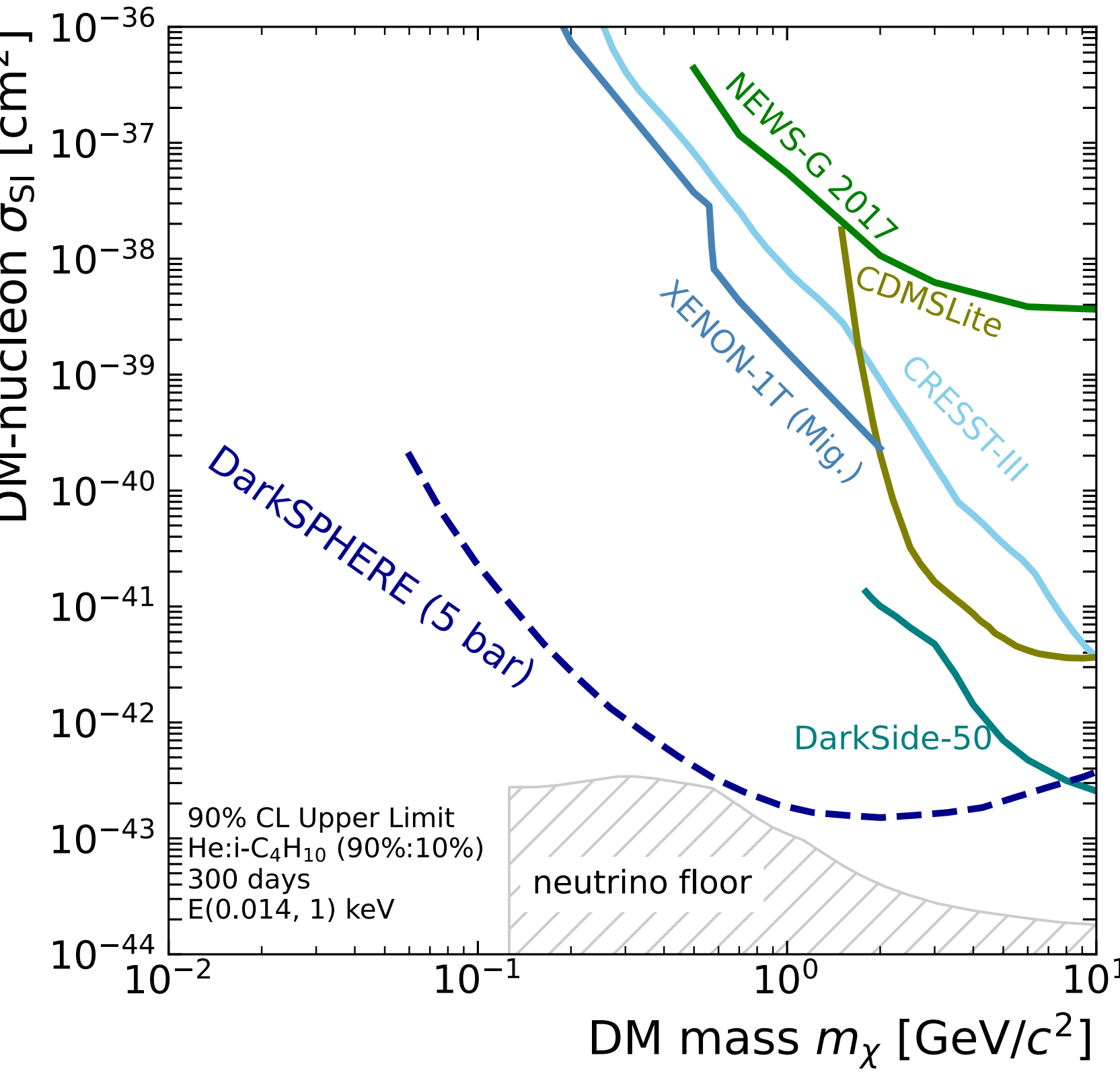
Rough sketch for scale
with $\varnothing 30$ cm DarkSPHERE



From: L Kneale, IOP HEPP&APP 2023

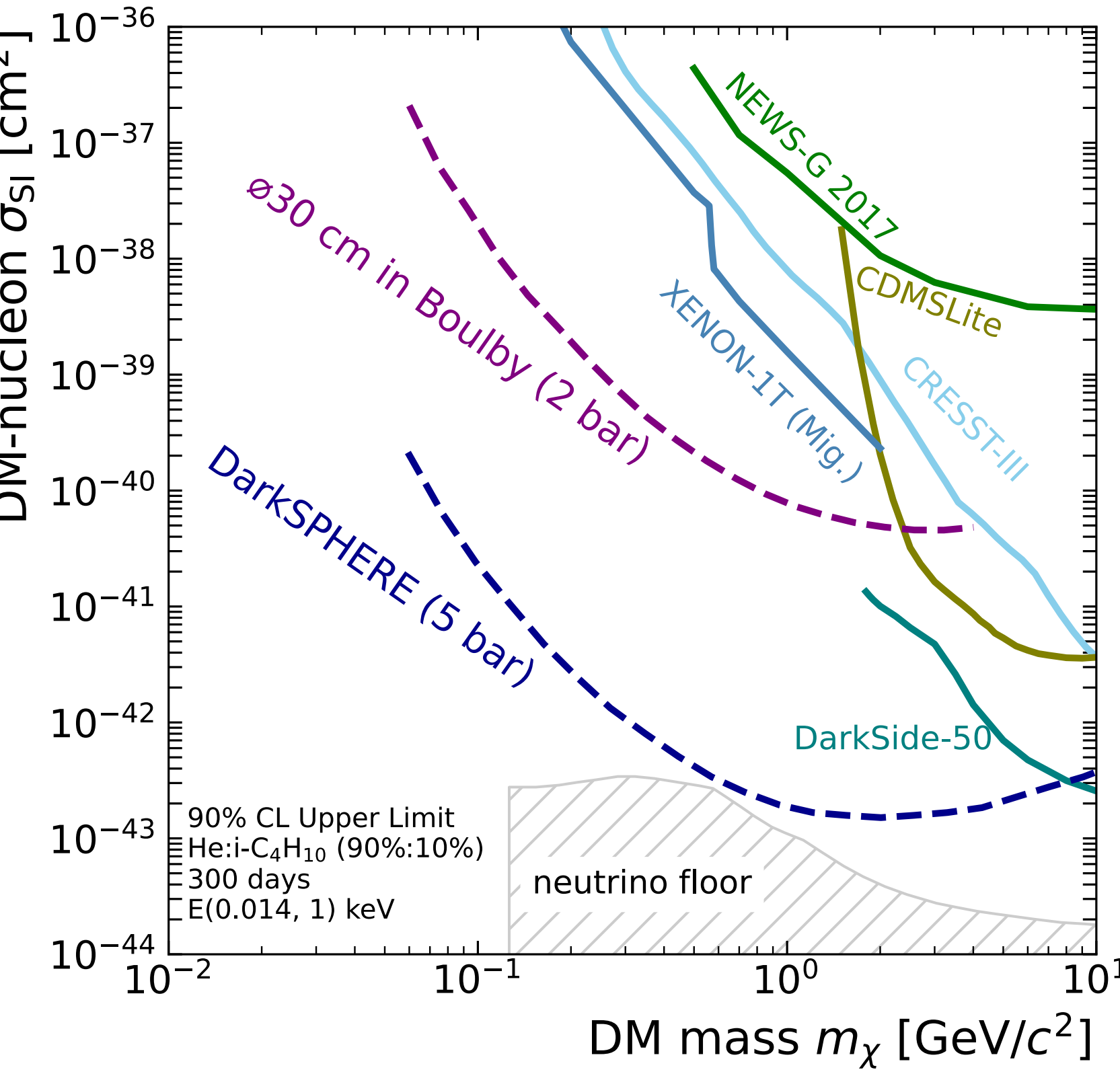
See A Tarrant's Talk, 9:00 Wednesday

DarkSPHERE Physics Potential



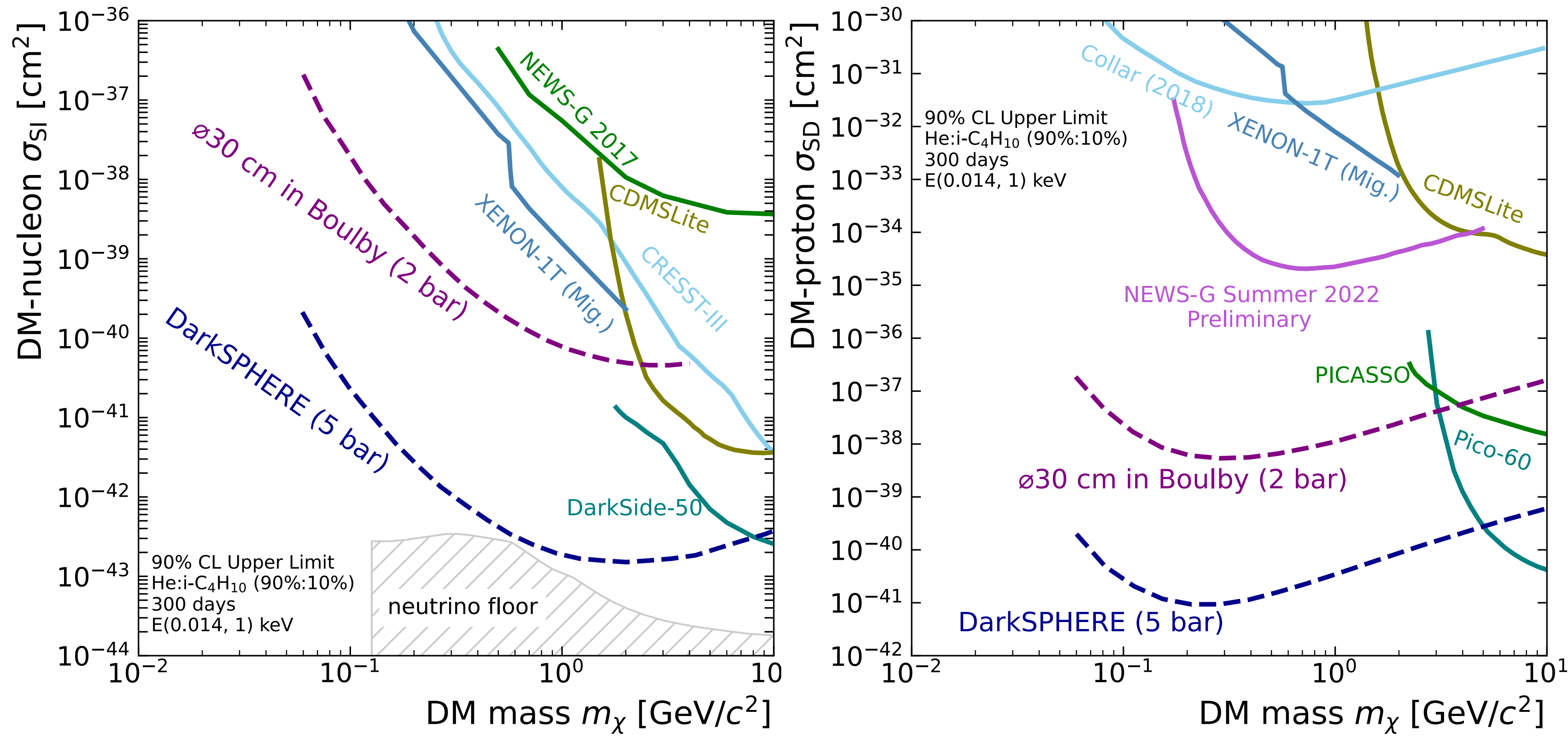
- ◆ **'Neutrino-floor' reaching potential** in DM-nucleon SI interactions
- ◆ **World-leading** potential in SD interactions through natural-abundance H and C isotopes
- ◆ $\varnothing 30\text{cm}$ prototype in Boulby in a DarkSPHERE-like shield will have world-leading sensitivity

DarkSPHERE Physics Potential



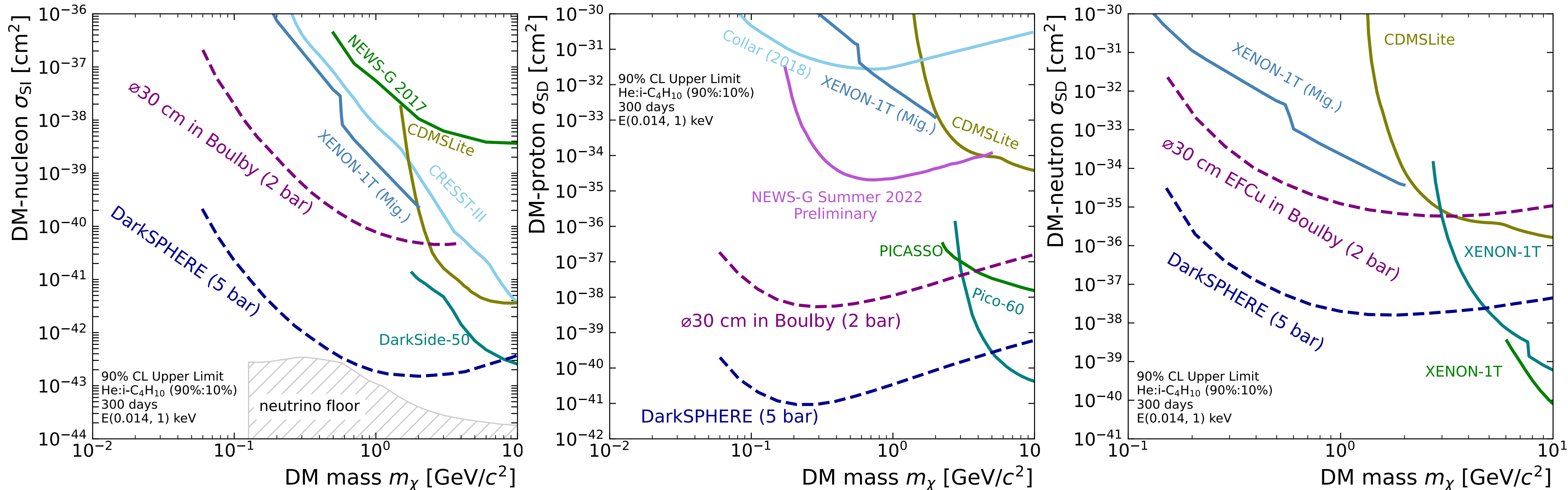
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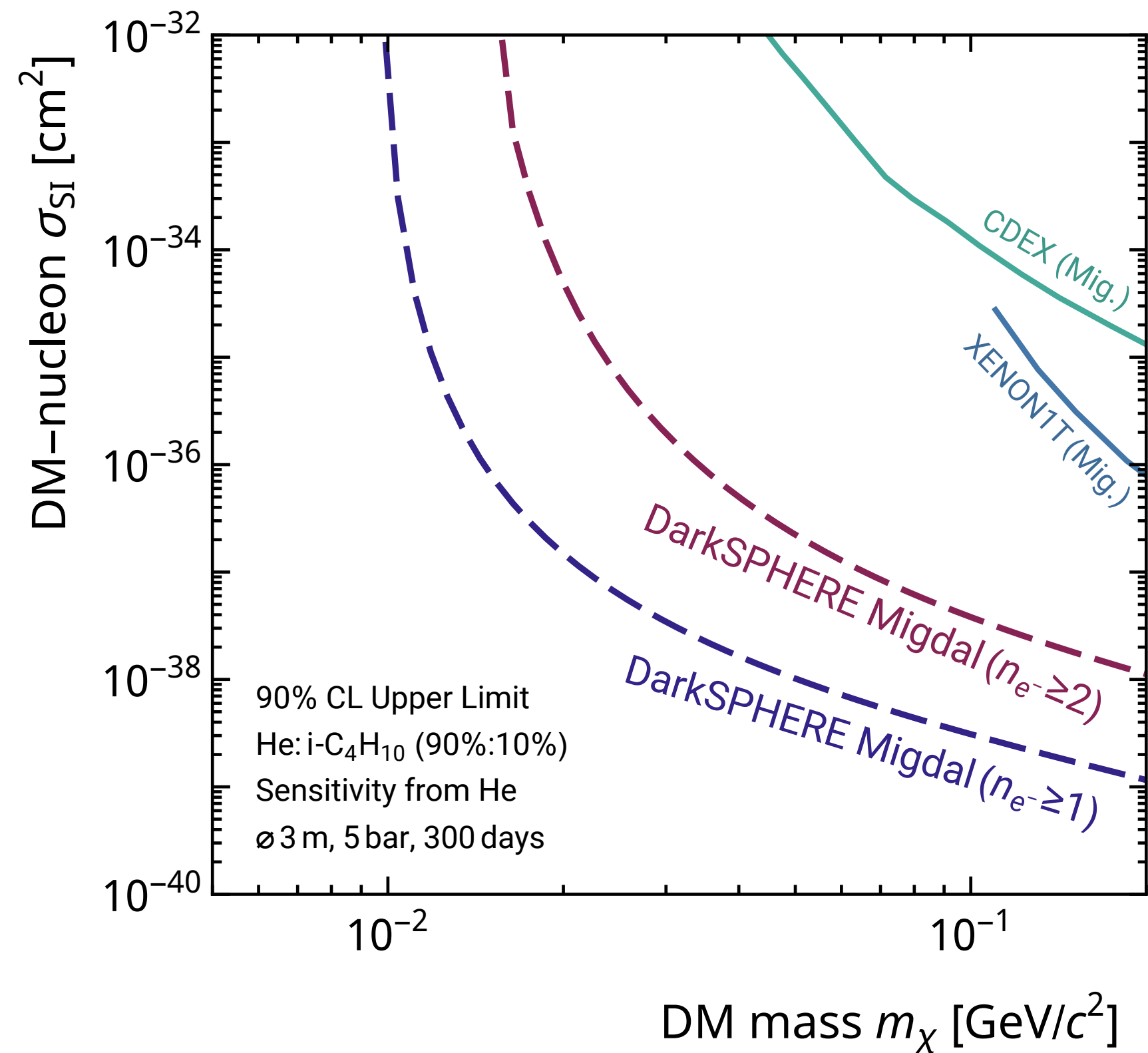
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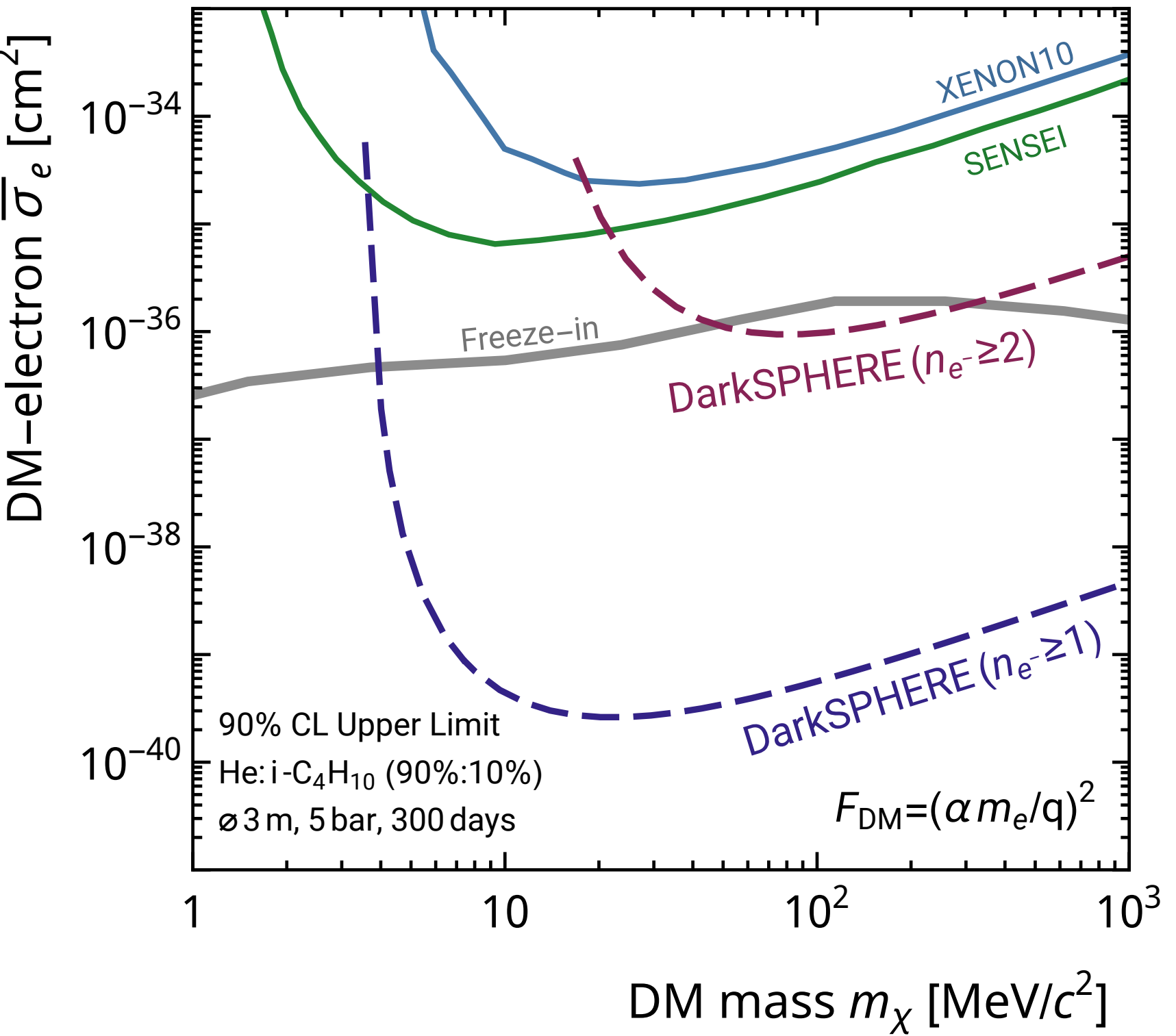
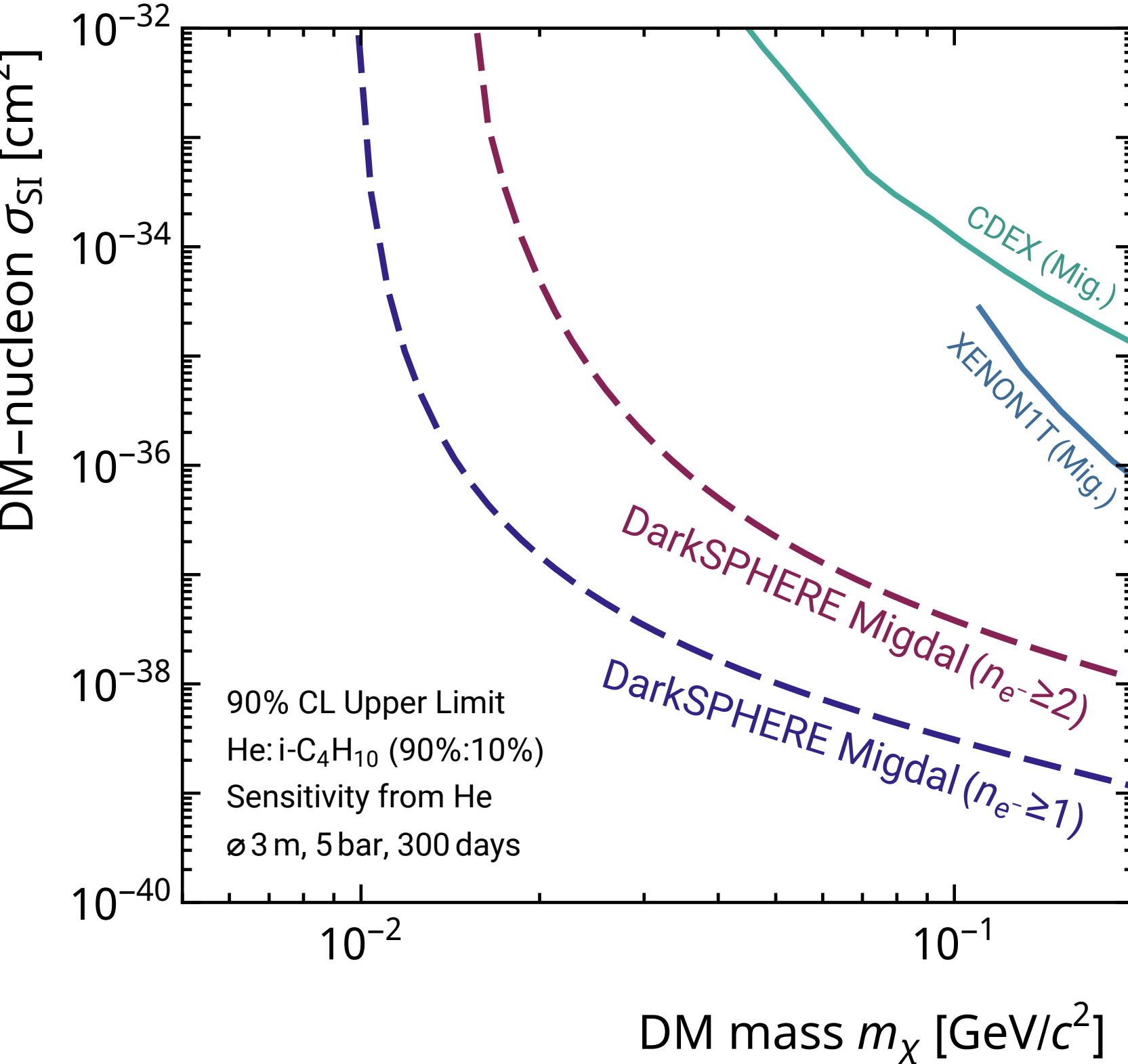
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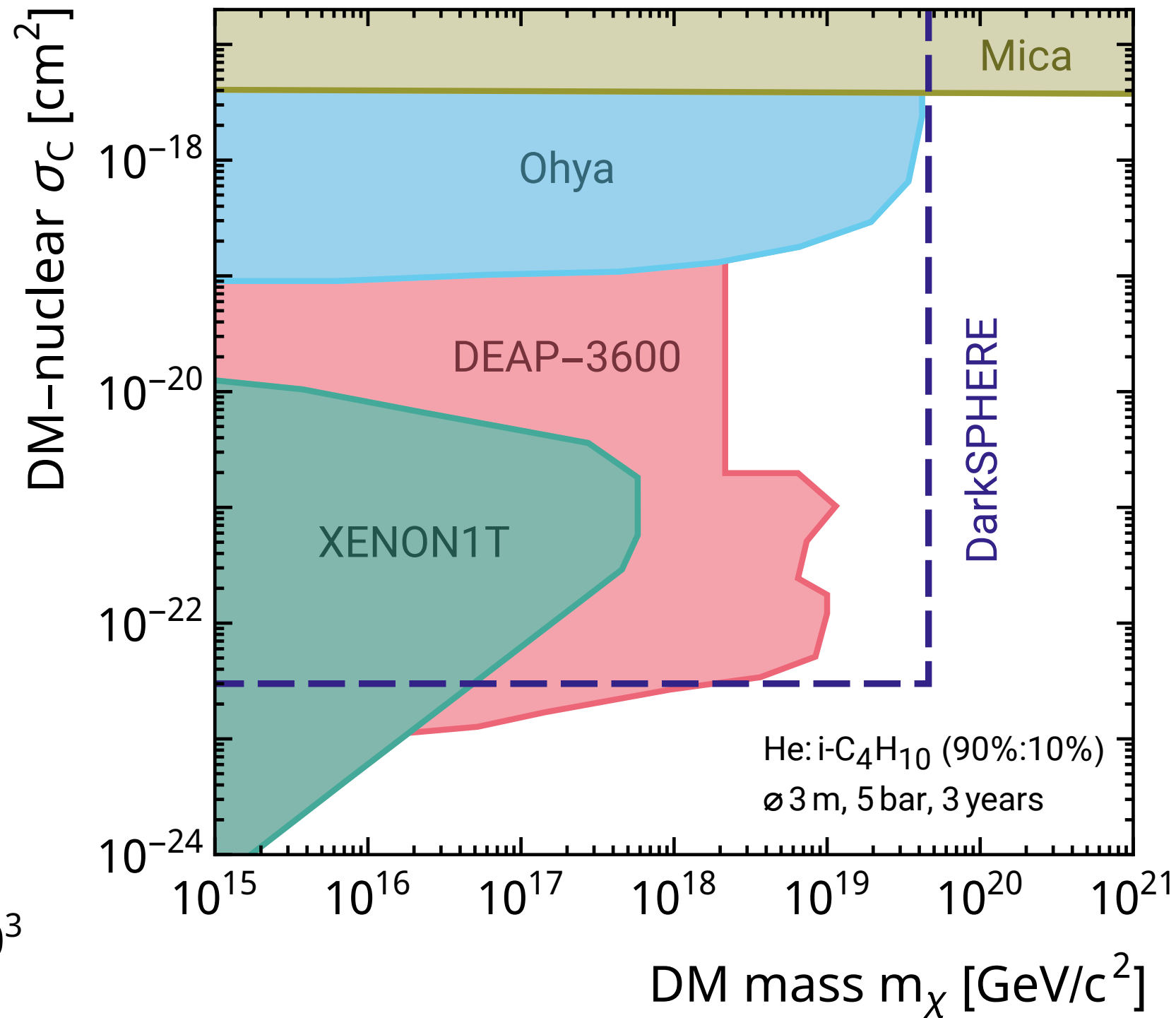
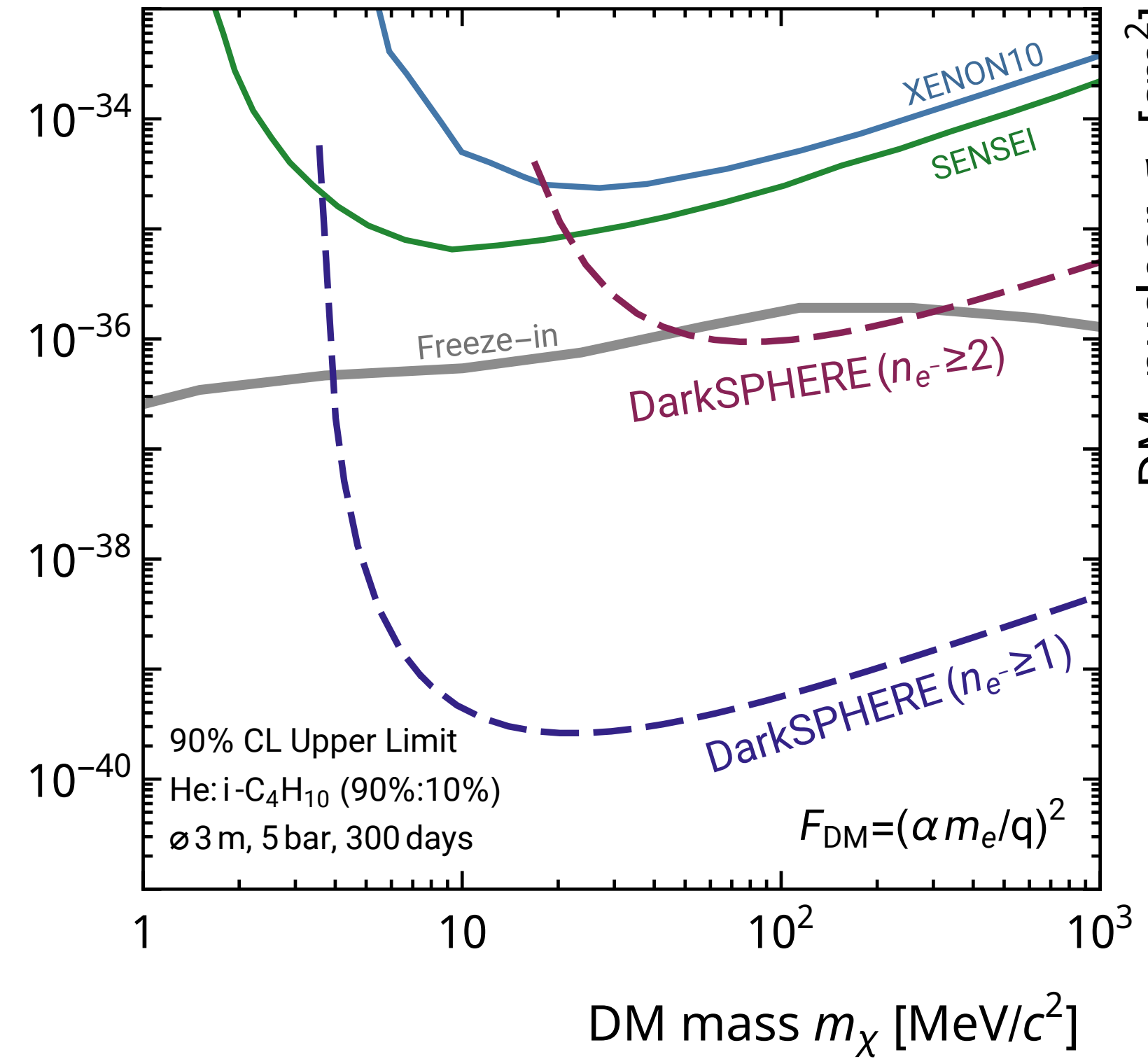
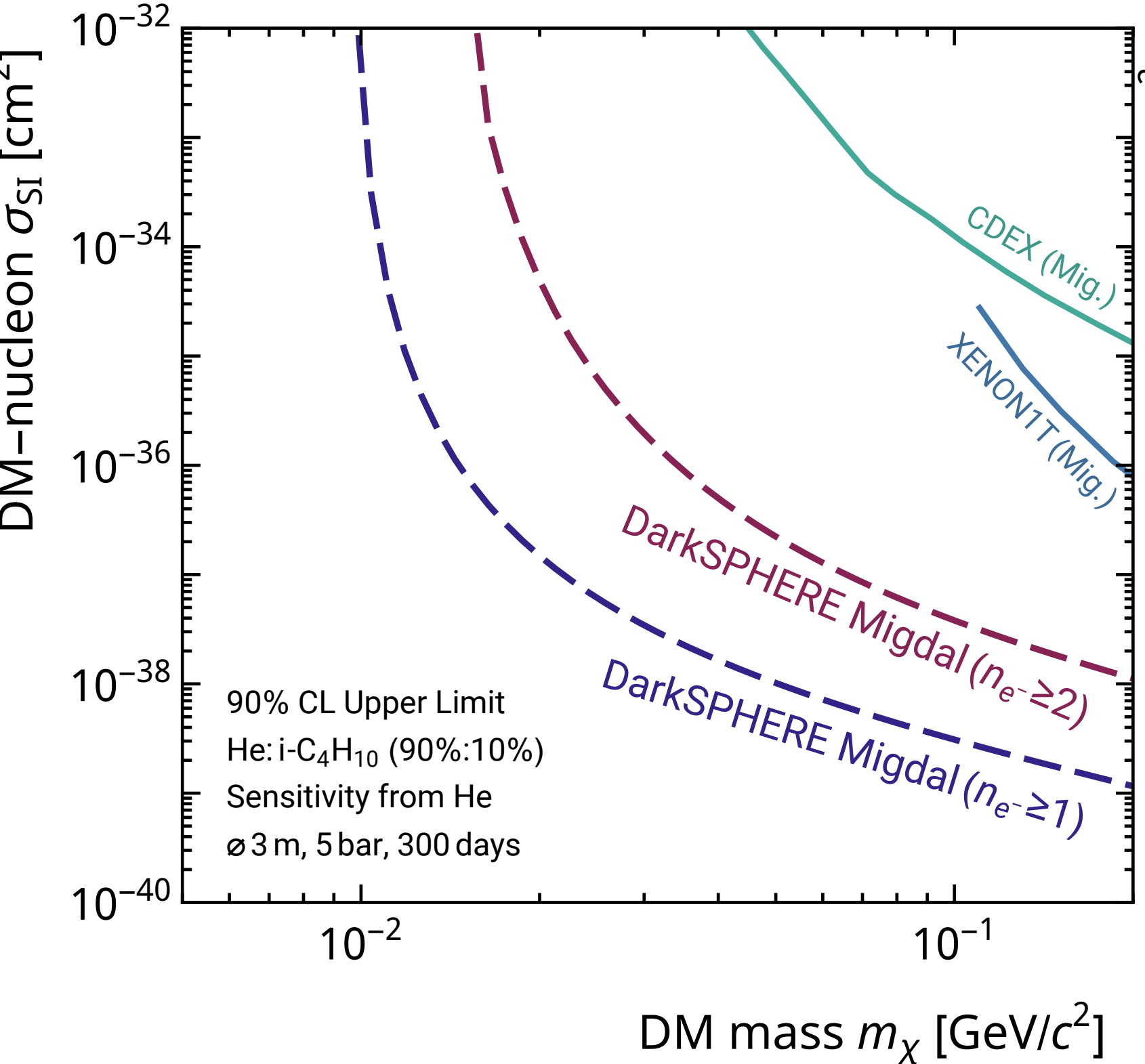
- Enhanced sensitivity through **MIGDAL effect** in nuclear scattering
- Sensitivity to electron scattering through low threshold
- DarkSPHERE can also study more **exotic candidates**

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Summary



- ◆ Spherical proportional counters well suited to explore light DM candidates
- ◆ **NEWS-G** completed first physics campaign in SNOLAB → analysis ongoing
- ◆ Fully electroformed SPCs will overcome main background
 - ➔ **DarkSPHERE** planned for current Boulby lab space
 - ➔ Funding to physics in 5 years
 - ➔ 30 cm fully EFCu detector to begin construction this year

