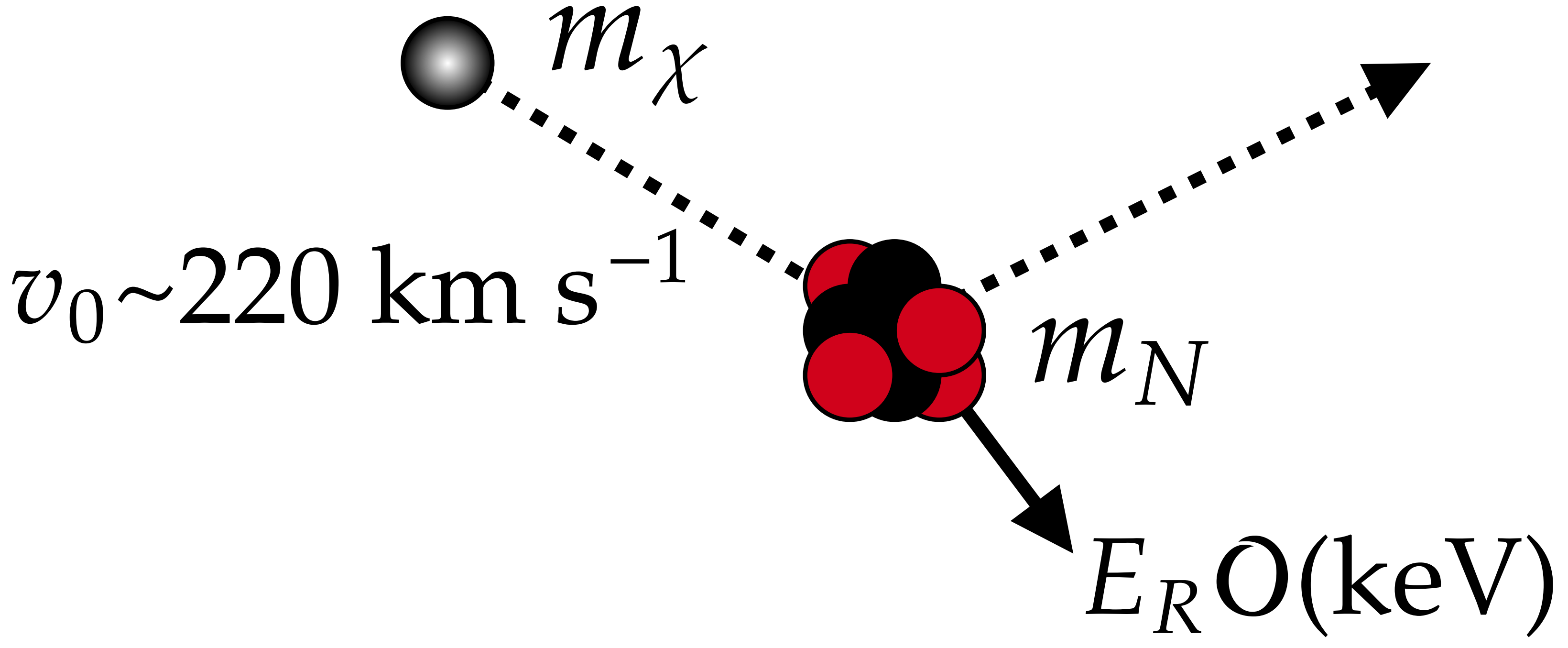
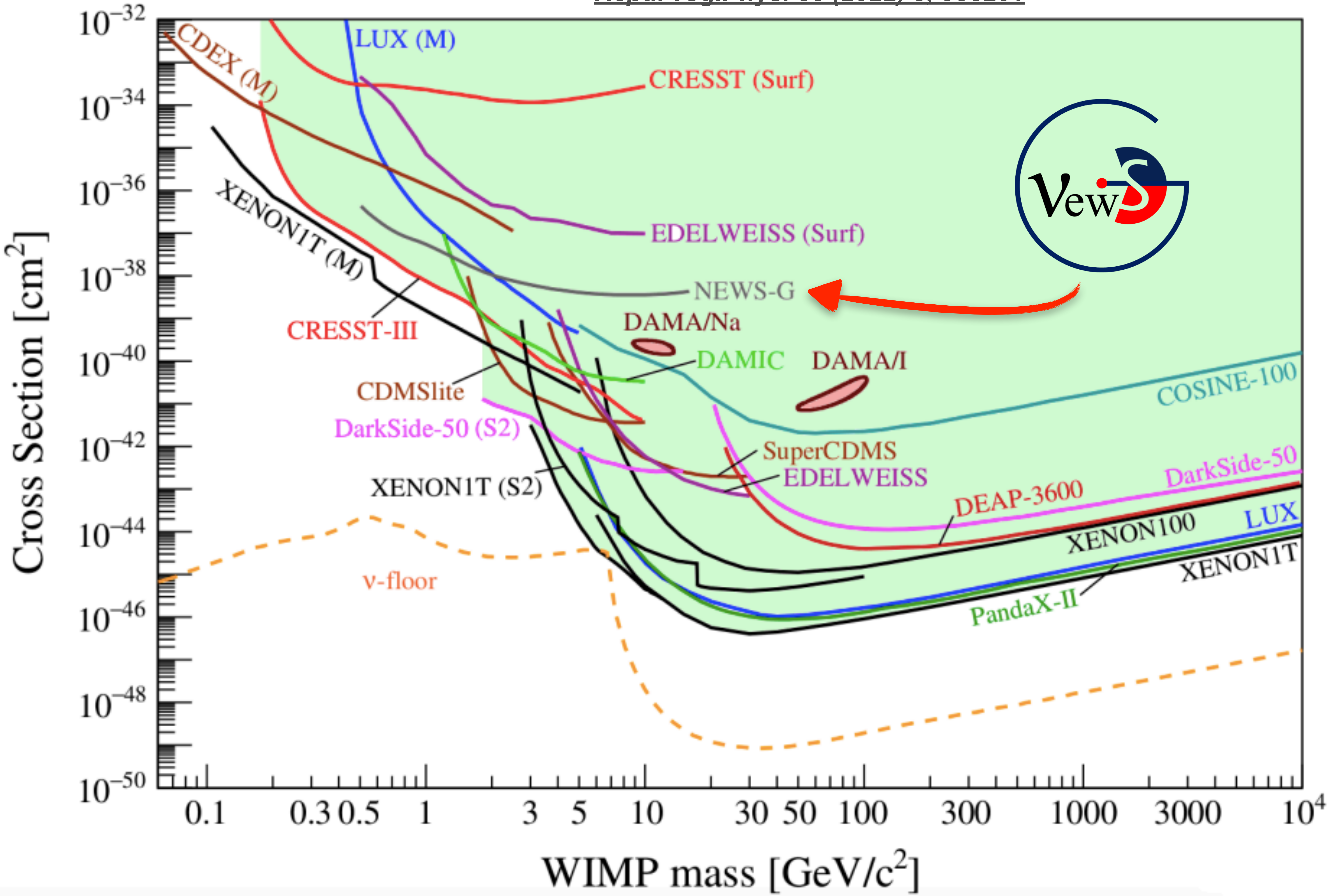
Recent Results from NEWS-G

P. Knights
University of Birmingham, UK

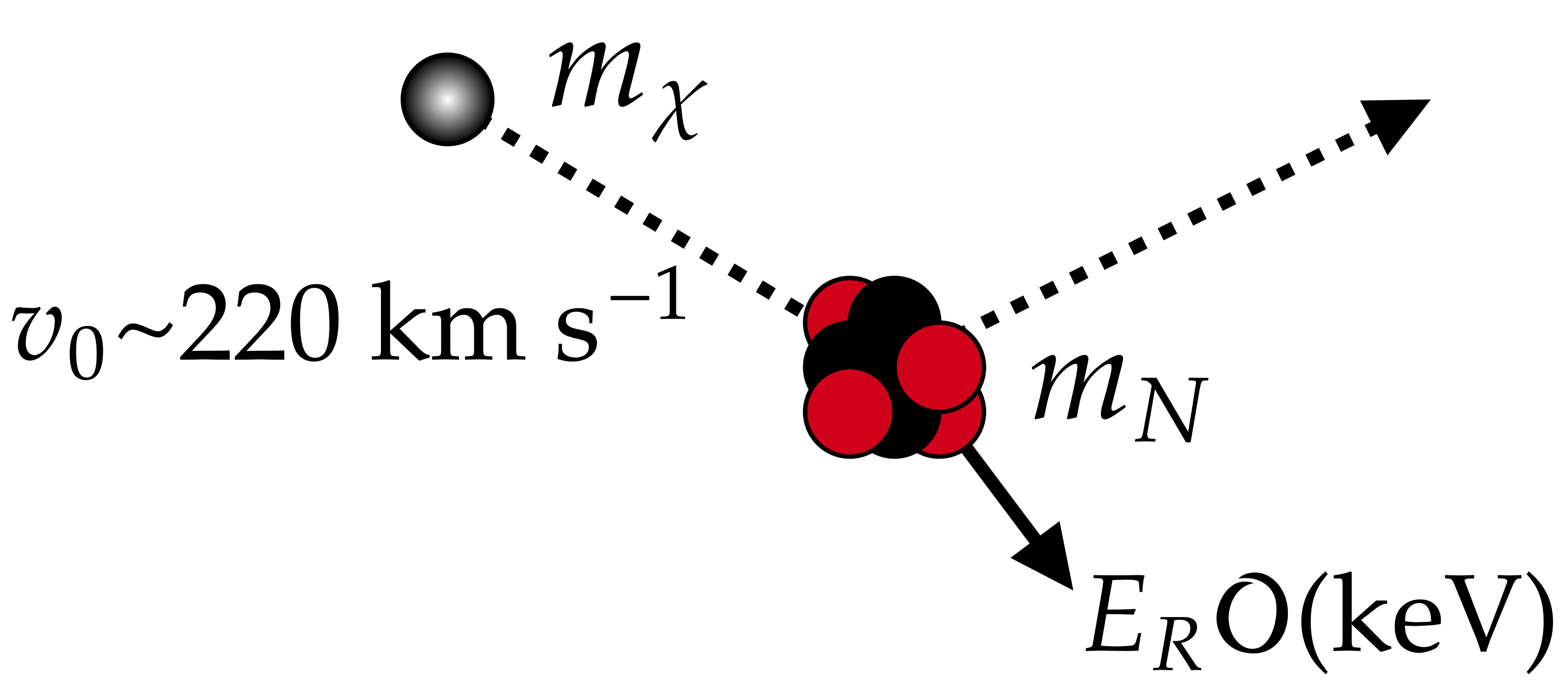
The Search for Light Dark Matter



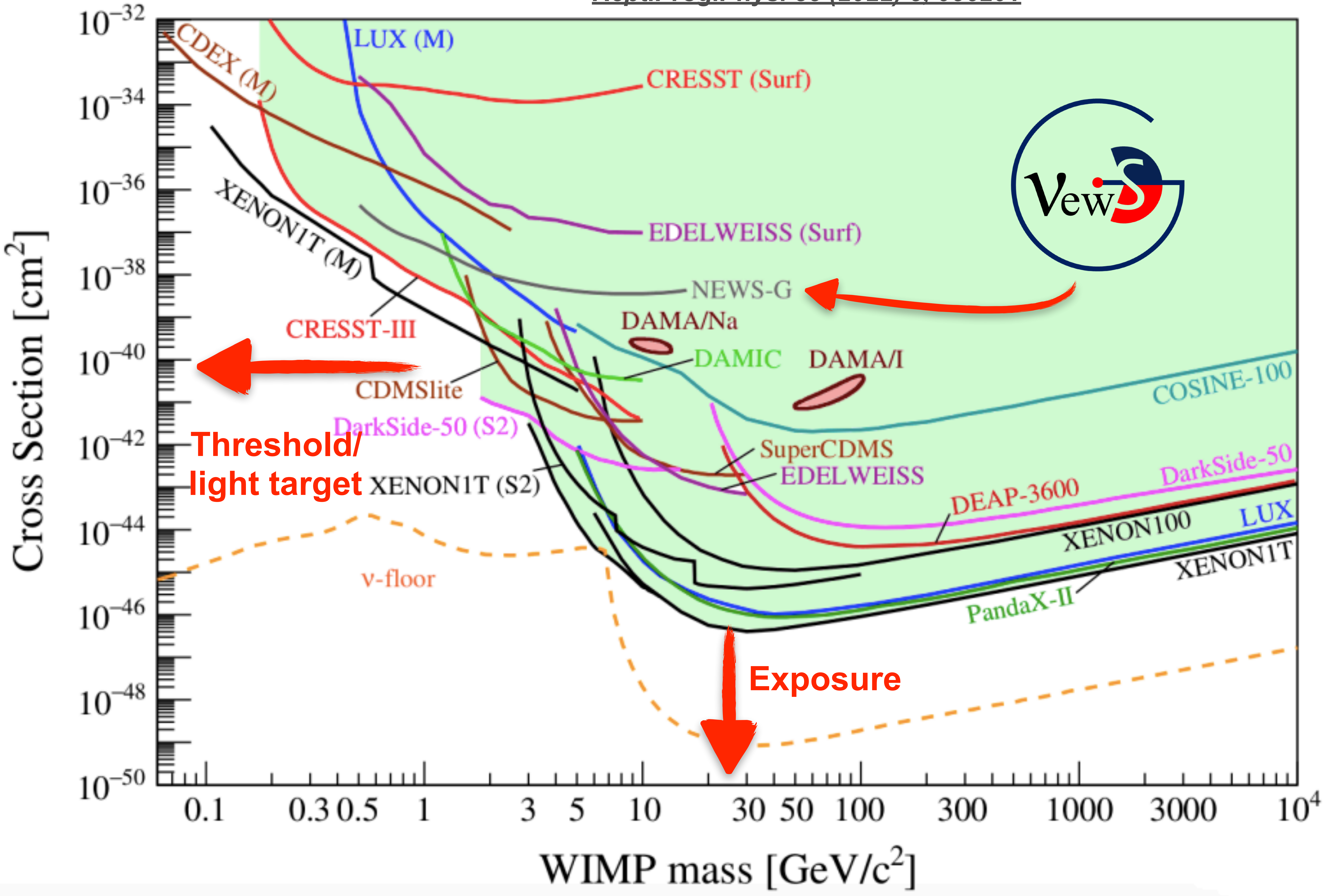
Rept.Prog.Phys. 85 (2022) 5, 056201



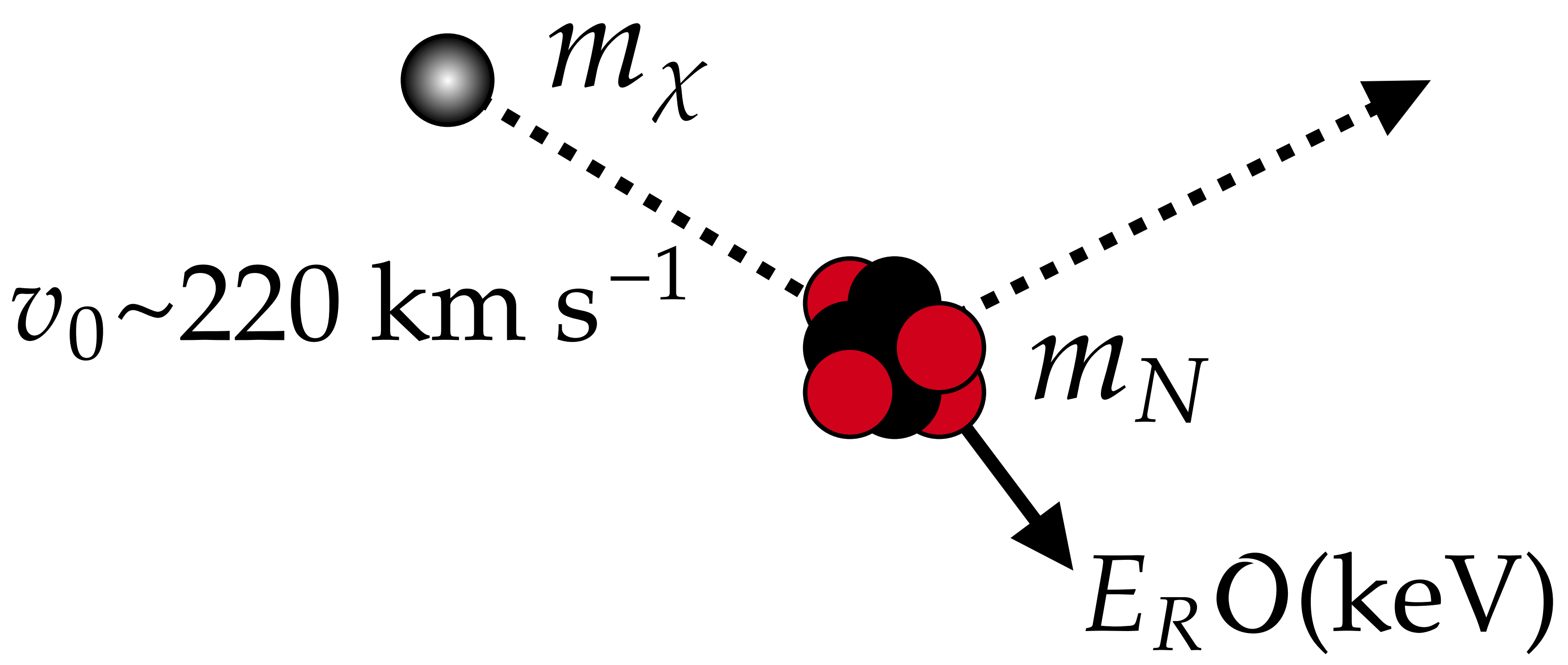
The Search for Light Dark Matter



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



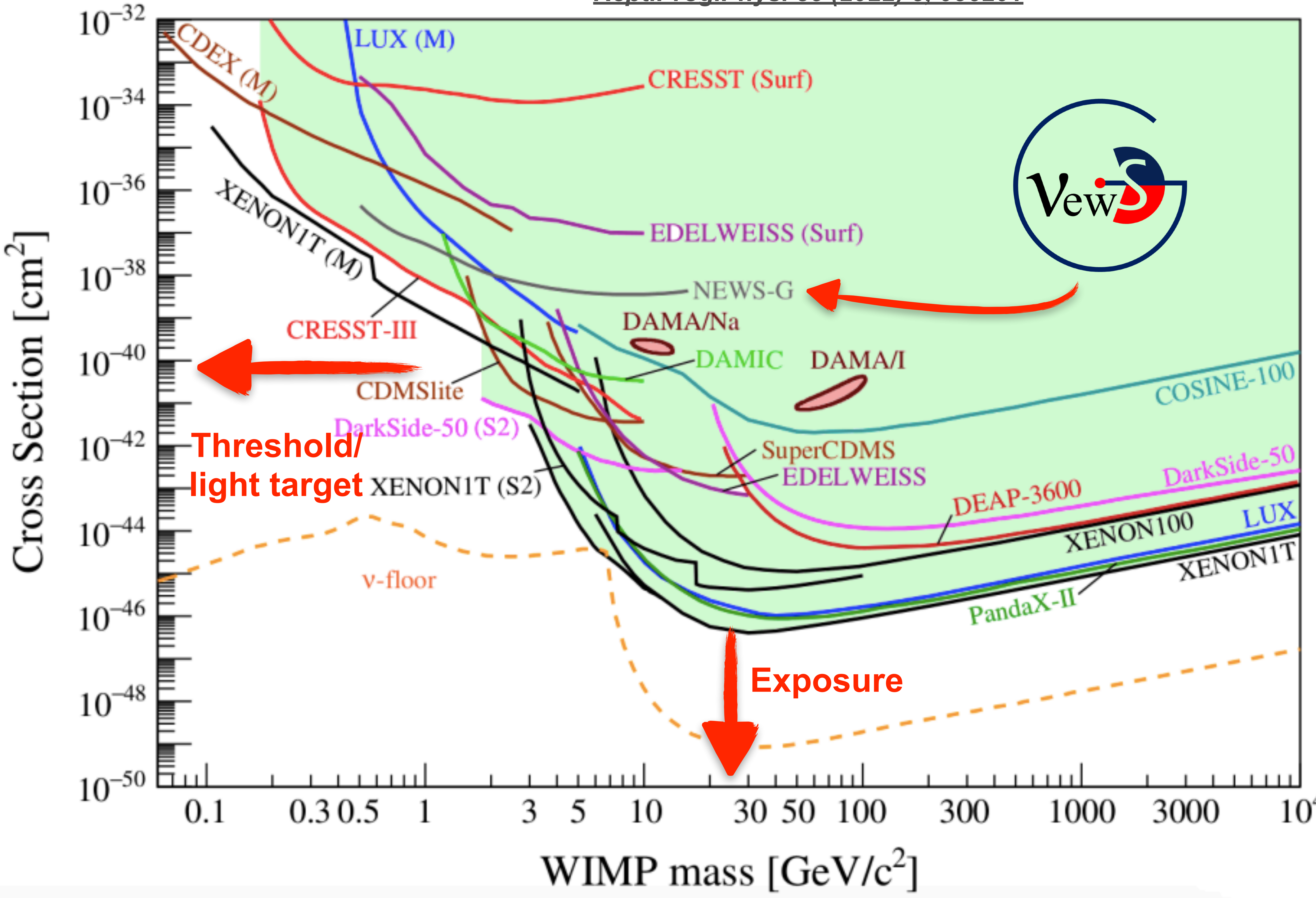
The Search for Light Dark Matter



- Light DM region has **attracted theoretical** interest

- **Exploring light DM** with nuclear recoils requires:
  - **Low energy threshold**
  - **Low-mass target nuclei**

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



NEWS-G

New Experiments With Spheres - Gas

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

Queen's University

CEA

SNOLAB

UKRI Science and Technology Facilities Council

Boulby Underground Laboratory

University of Birmingham

RMC CMR

TRIUMF

Subatech

University of Alberta

LPSC Grenoble

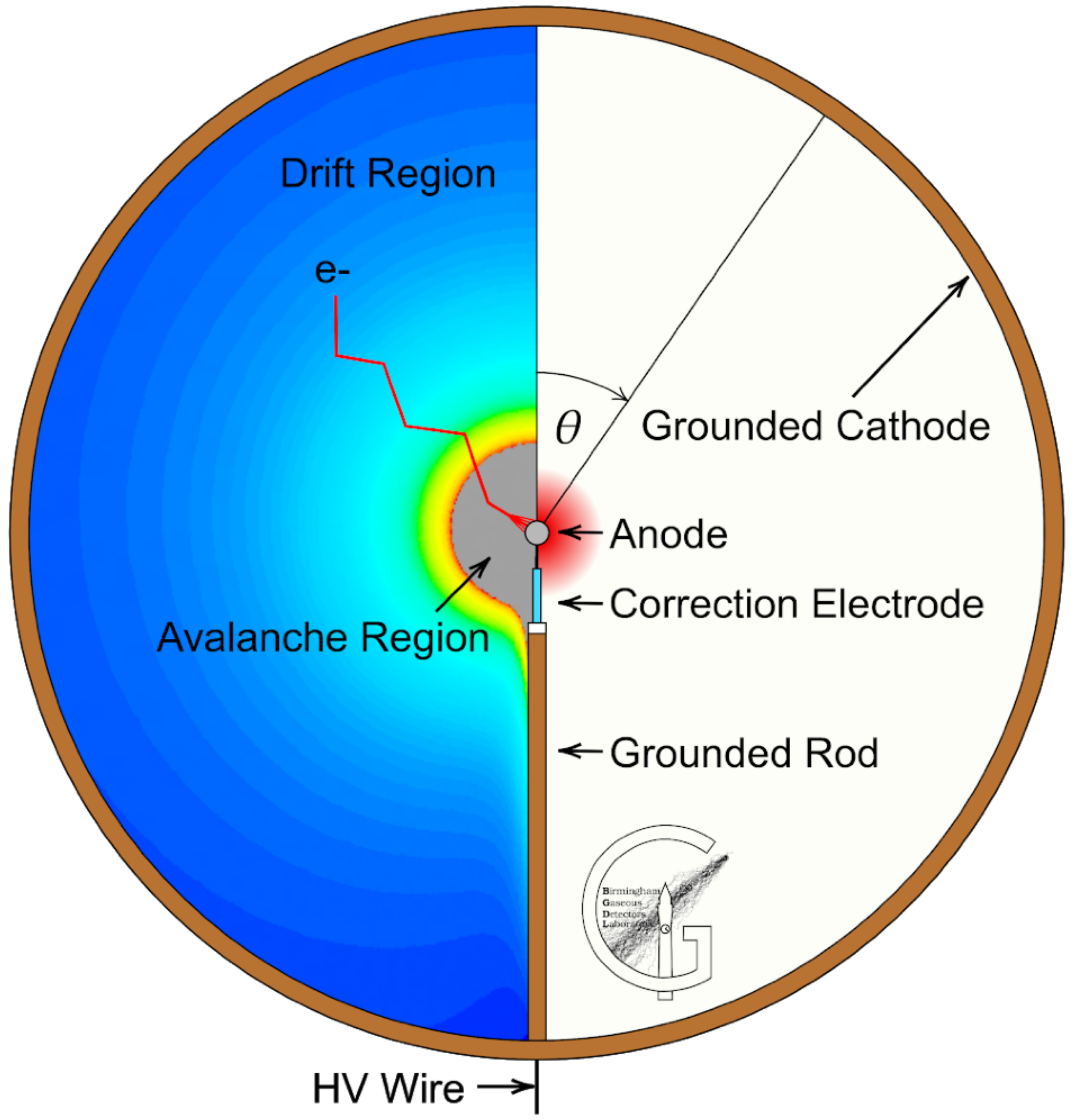
Pacific Northwest National Laboratory

Aristotle University of Thessaloniki

Spherical Proportional Counters

- Simplest form: **~ mm ball** in a **~0.1-1 m spherical shell**
- Ideal electric field varies as $1/r^2$
  - **Naturally divides** detector: **drift** and **avalanche regions**

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

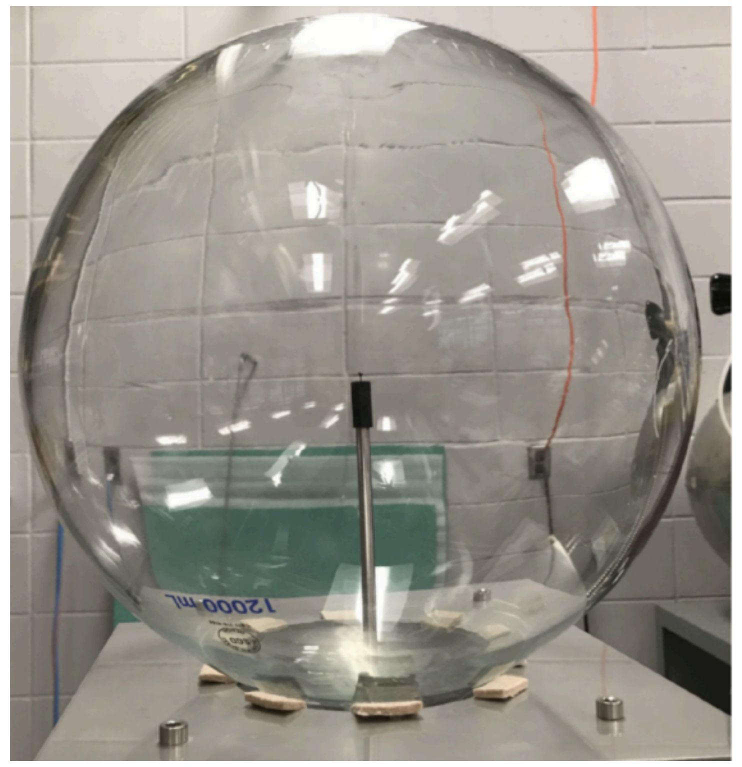


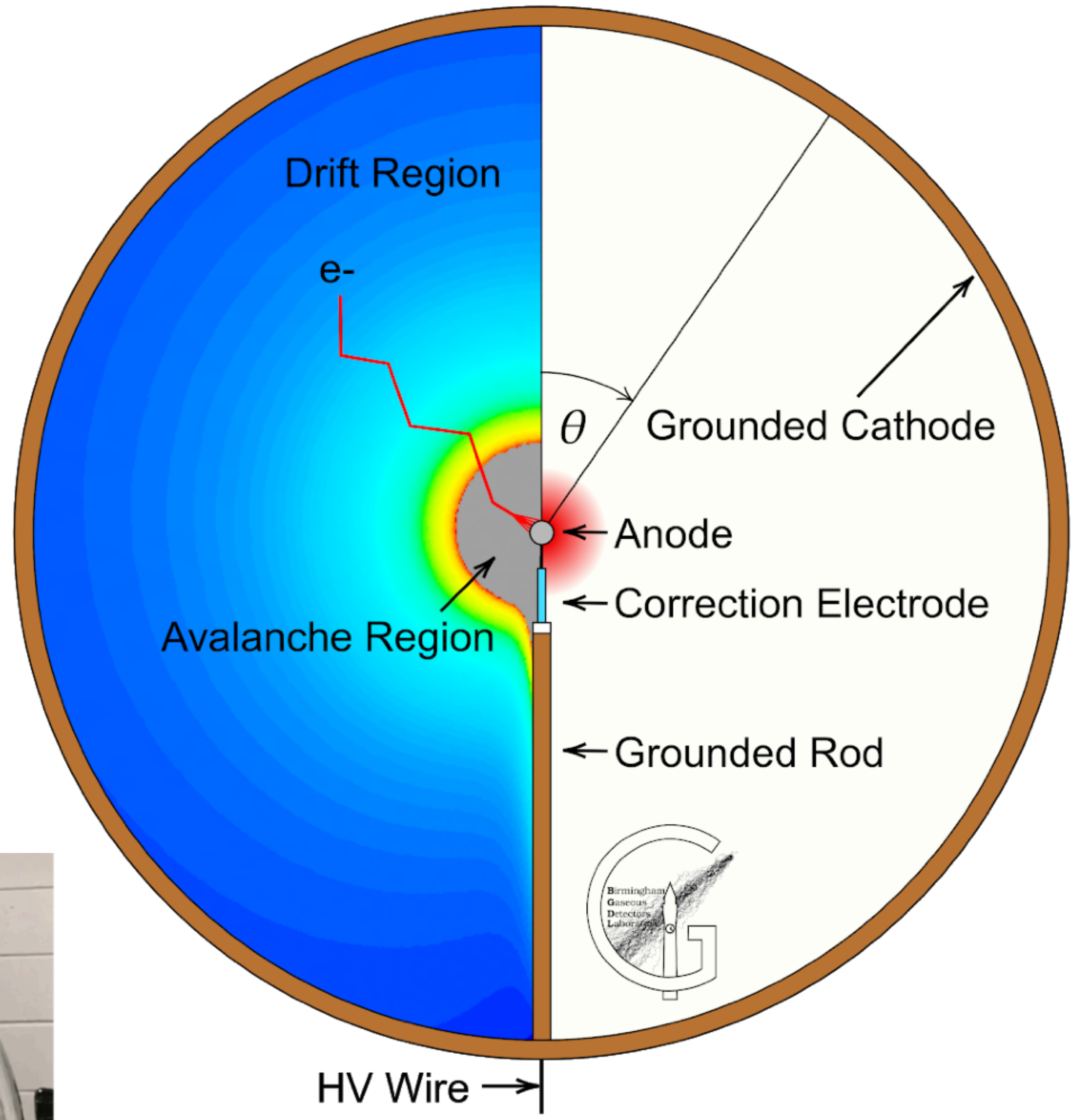
JINST 15 (2020) 06, C06013

Spherical Proportional Counters

- Simplest form: **~ mm ball** in a **~0.1-1 m spherical shell**
- Ideal electric field varies as $1/r^2$
  - **Naturally divides** detector: **drift** and **avalanche regions**

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



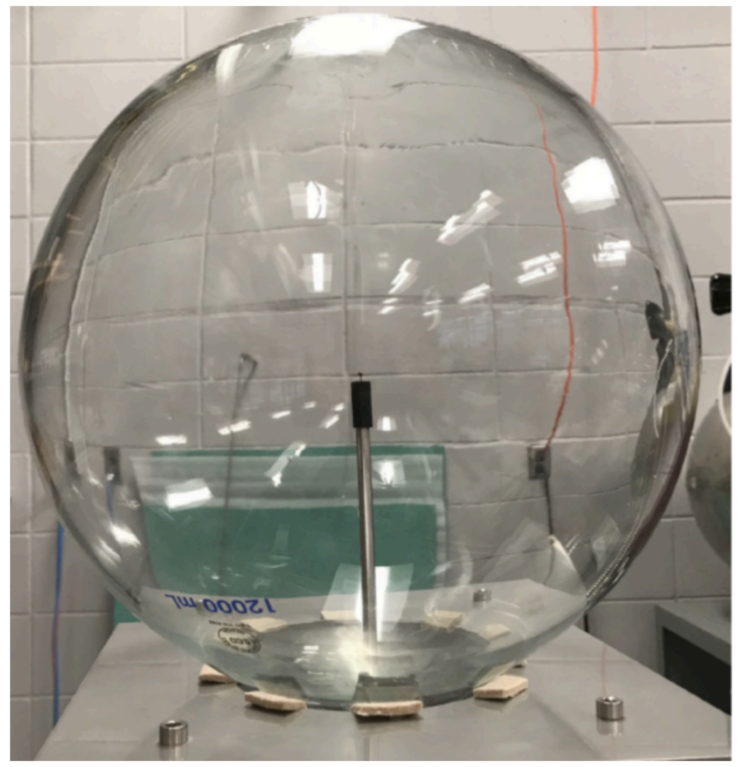


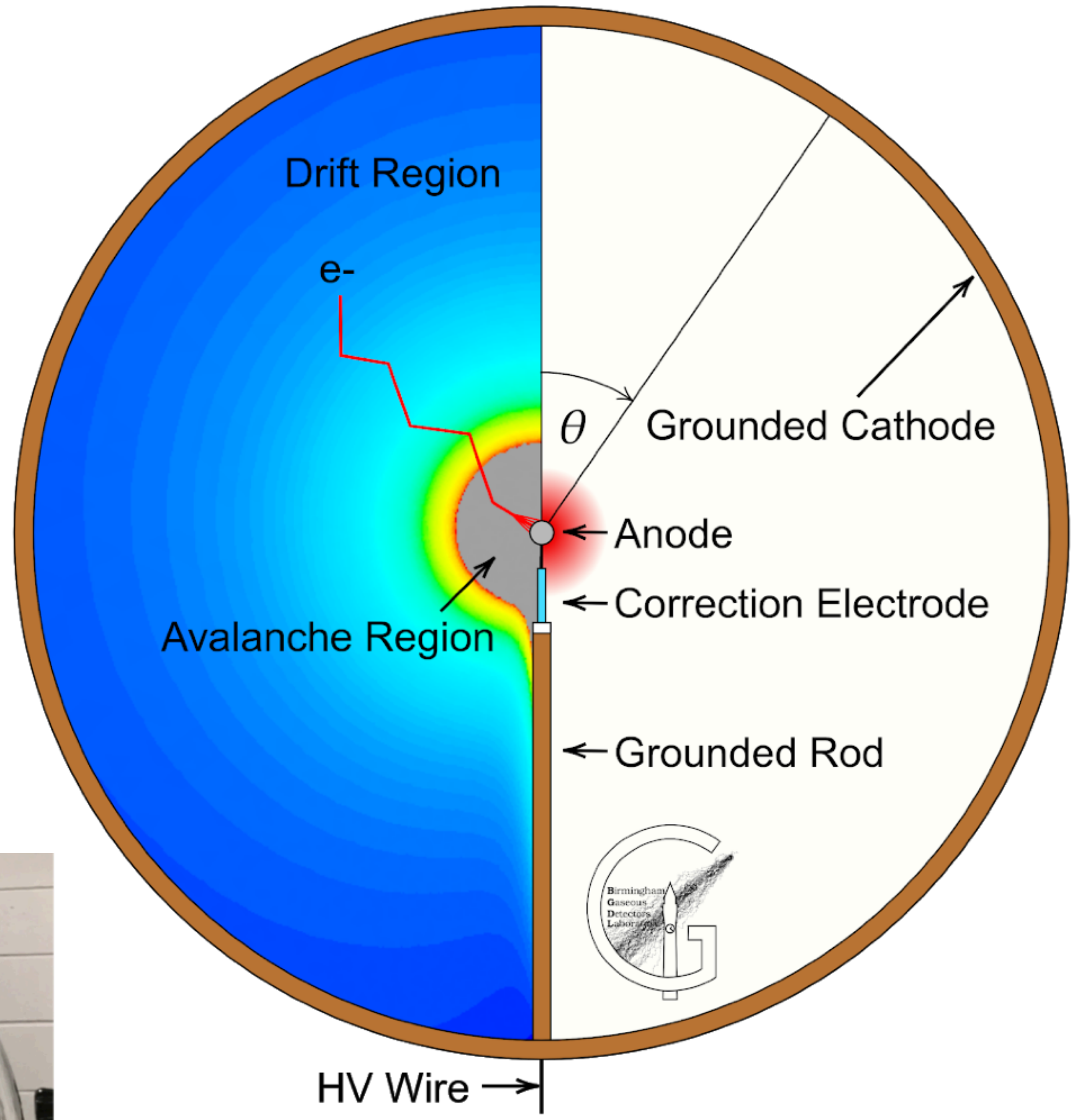
JINST 15 (2020) 06, C06013

Spherical Proportional Counters

- Simplest form: **~ mm ball** in a **~0.1-1 m spherical shell**
- Ideal electric field varies as $1/r^2$
  - **Naturally divides** detector: **drift** and **avalanche regions**

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





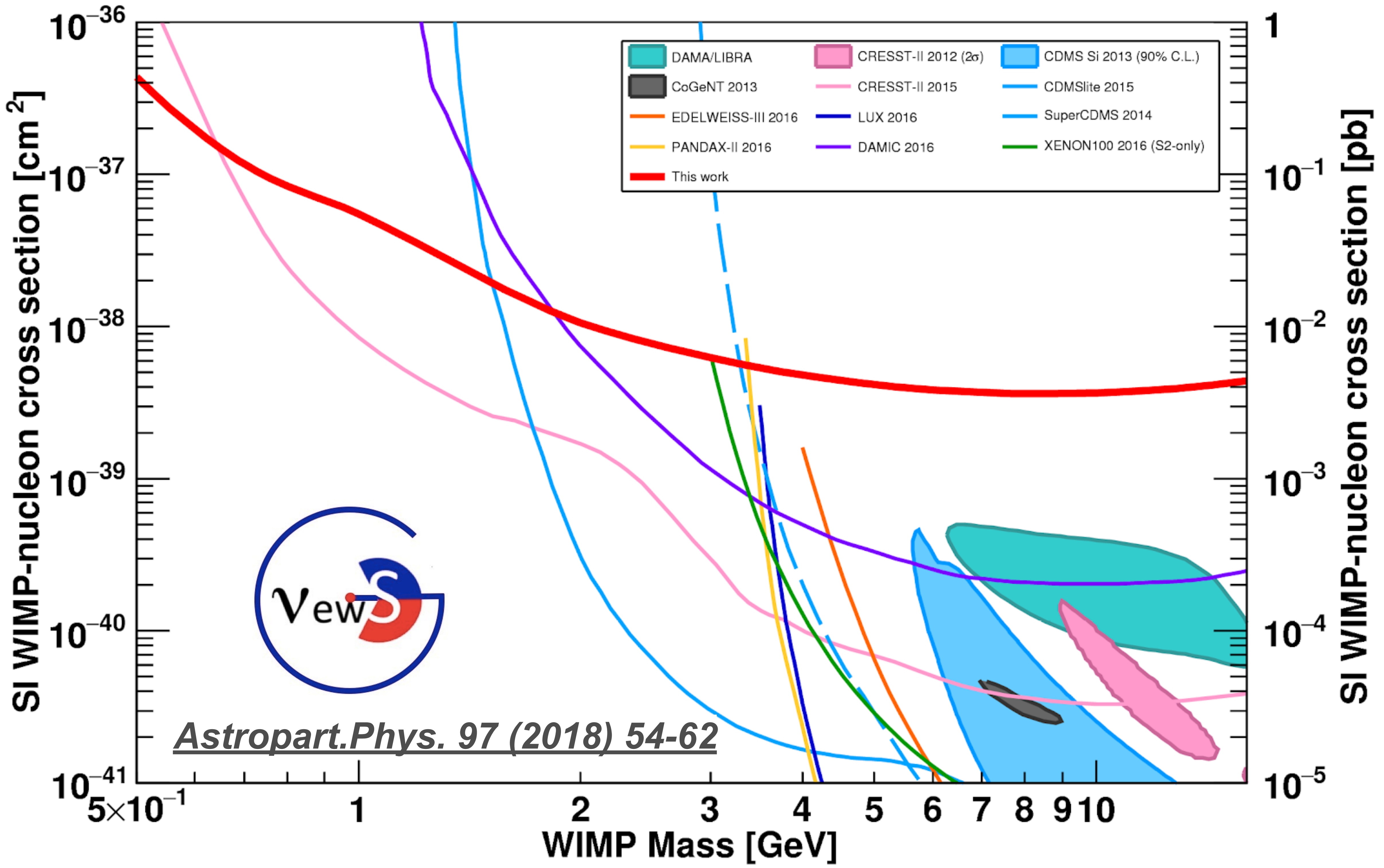
JINST 15 (2020) 06, C06013

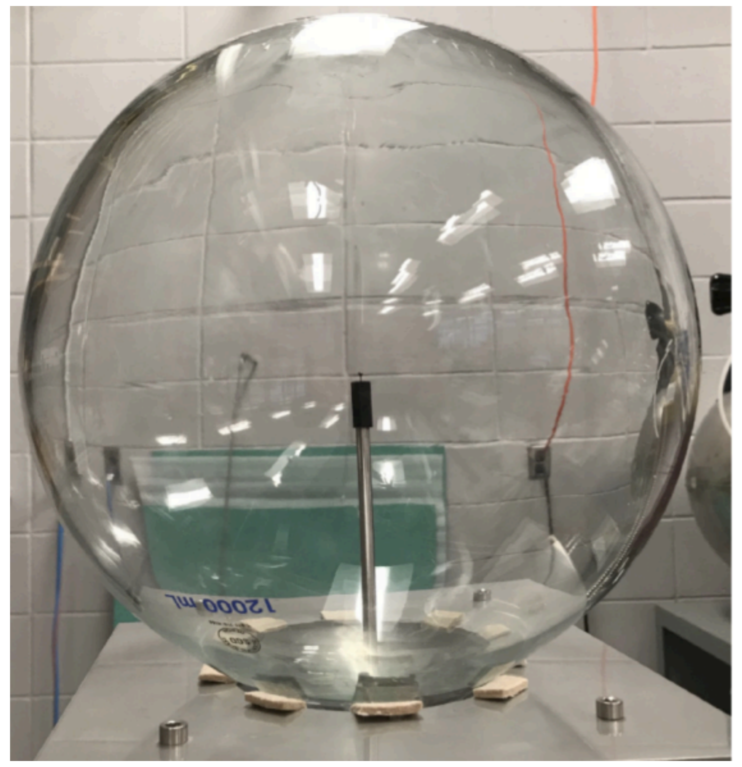
- **Low capacitance**, independent of detector size
  - Single-electron detection
- **Lowest surface area to volume ratio**
- Fiducialisation and PID from radial E-field
- **Choice of gas** targets (H, He, Ne) and pressures
  - Kinematic match to light-DM

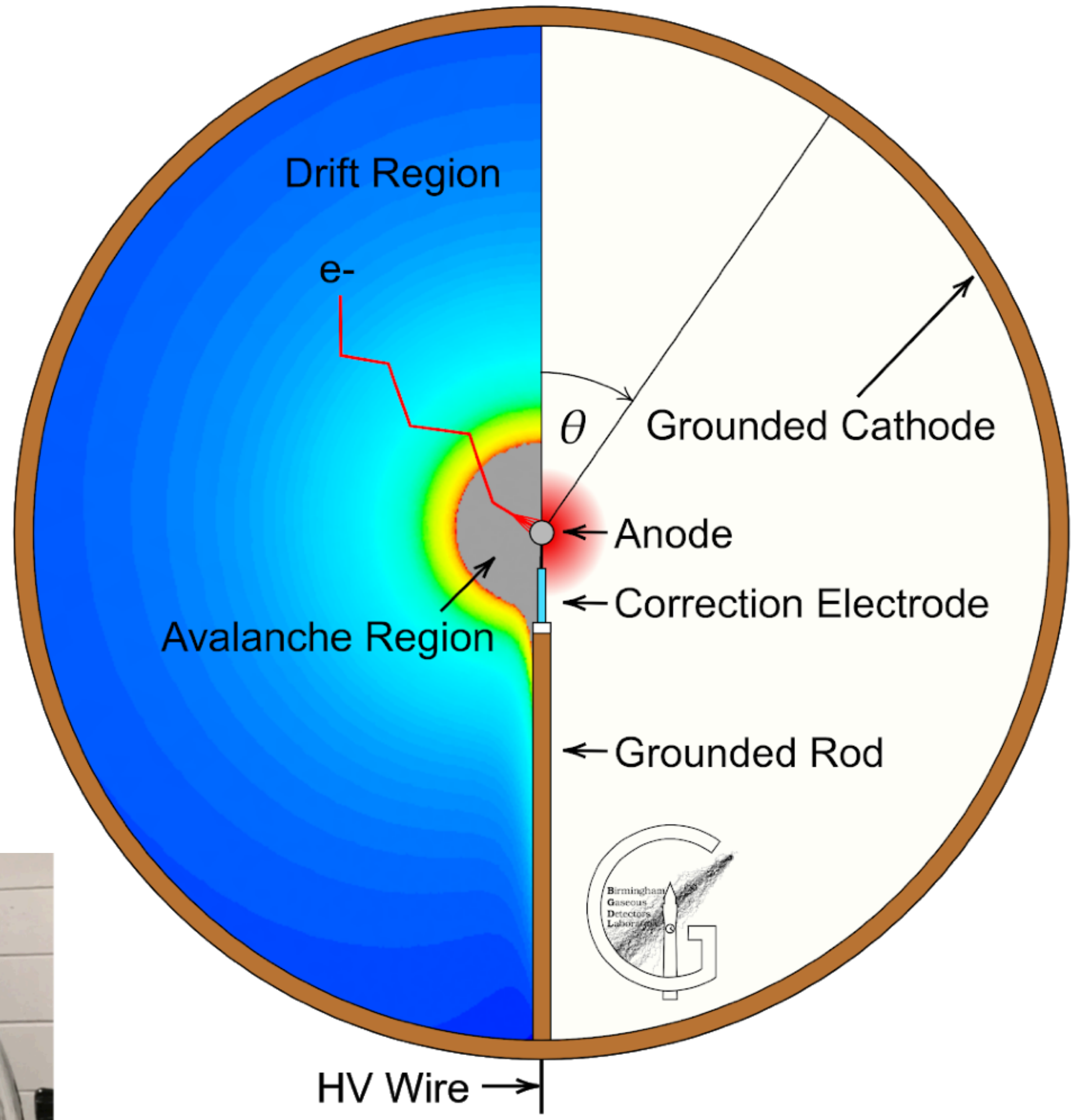
Spherical Proportional Counters

- Simplest form: **~ mm ball** in a **~0.1-1 m spherical shell**
- Ideal electric field varies as $1/r^2$
  - **Naturally divides** detector: **drift** and **avalanche regions**

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





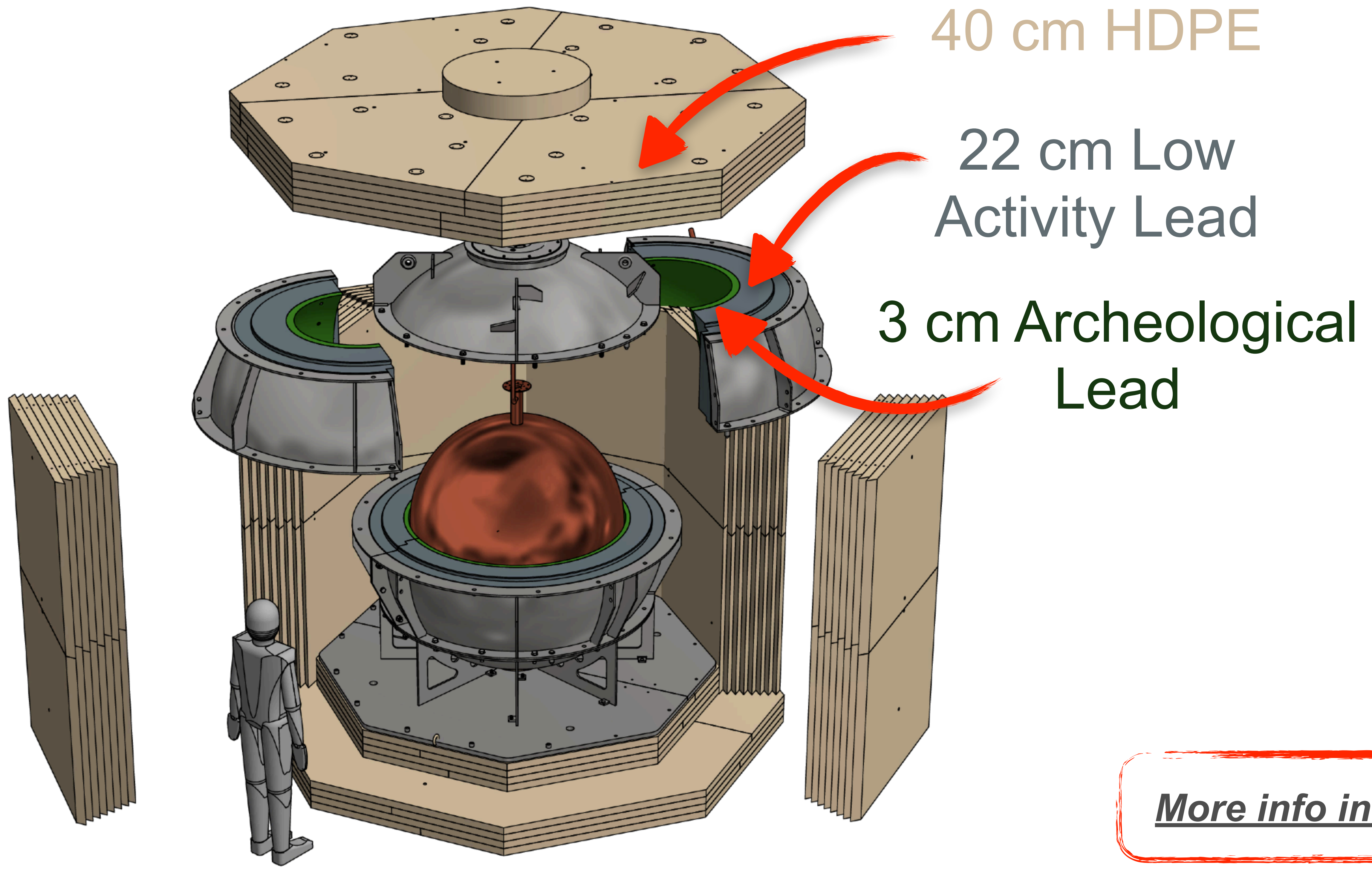


JINST 15 (2020) 06, C06013

- **Low capacitance**, independent of detector size
  - Single-electron detection
- **Lowest surface area to volume ratio**
- Fiducialisation and PID from radial E-field
- **Choice of gas** targets (H, He, Ne) and pressures
  - Kinematic match to light-DM

SNOGLOBE

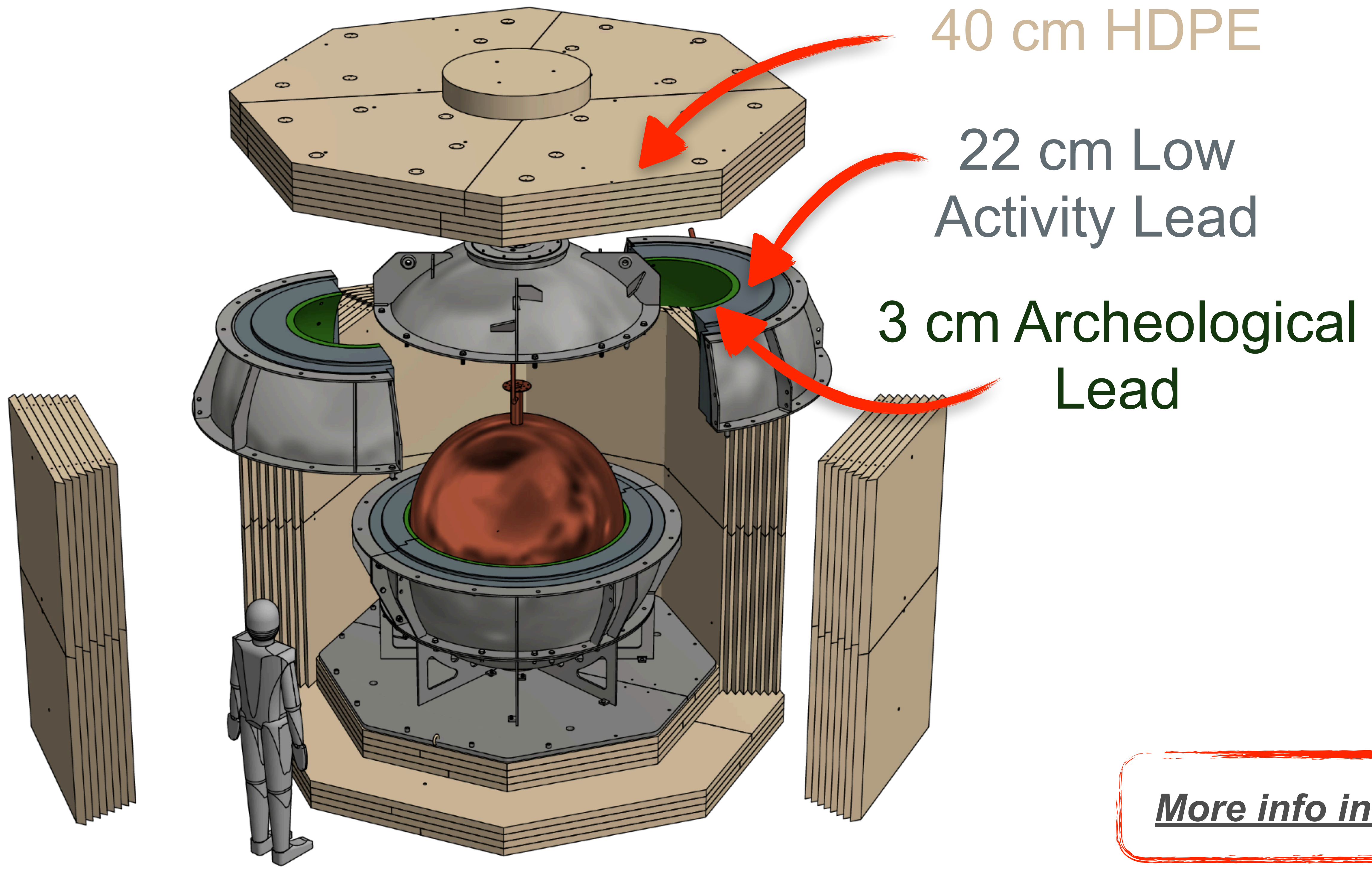
- New ⌀**140 cm detector**
- **4N** (99.99% pure) Aurubis copper
- Constructed and tested in LSM, France
- Now being commissioned in SNOLAB, Canada



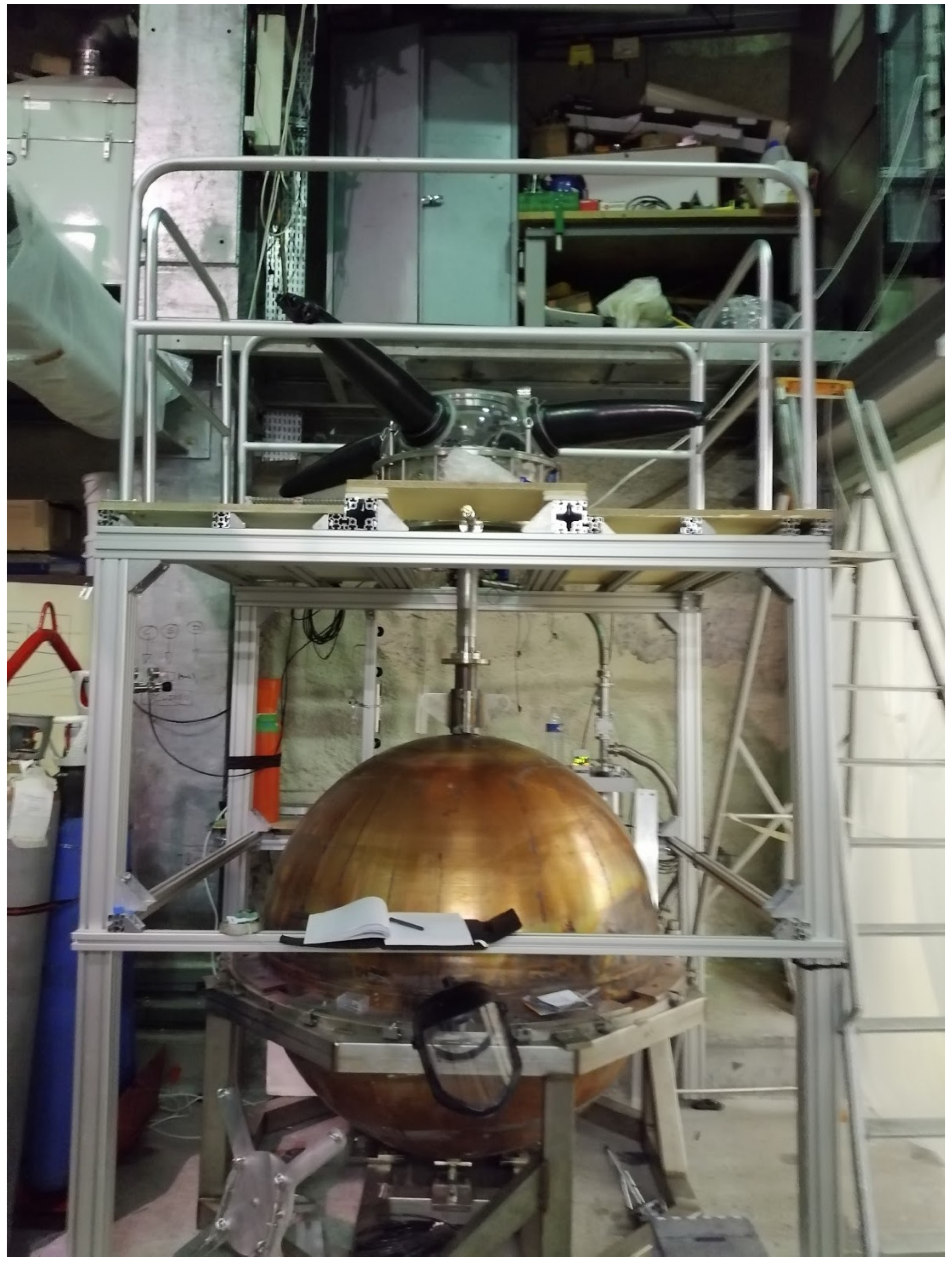
More info in recent article: arXiv 2205.15433

SNOGLOBE

- New ⌀**140 cm detector**
- **4N** (99.99% pure) Aurubis copper
- Constructed and tested in LSM, France
- Now being commissioned in SNOLAB, Canada



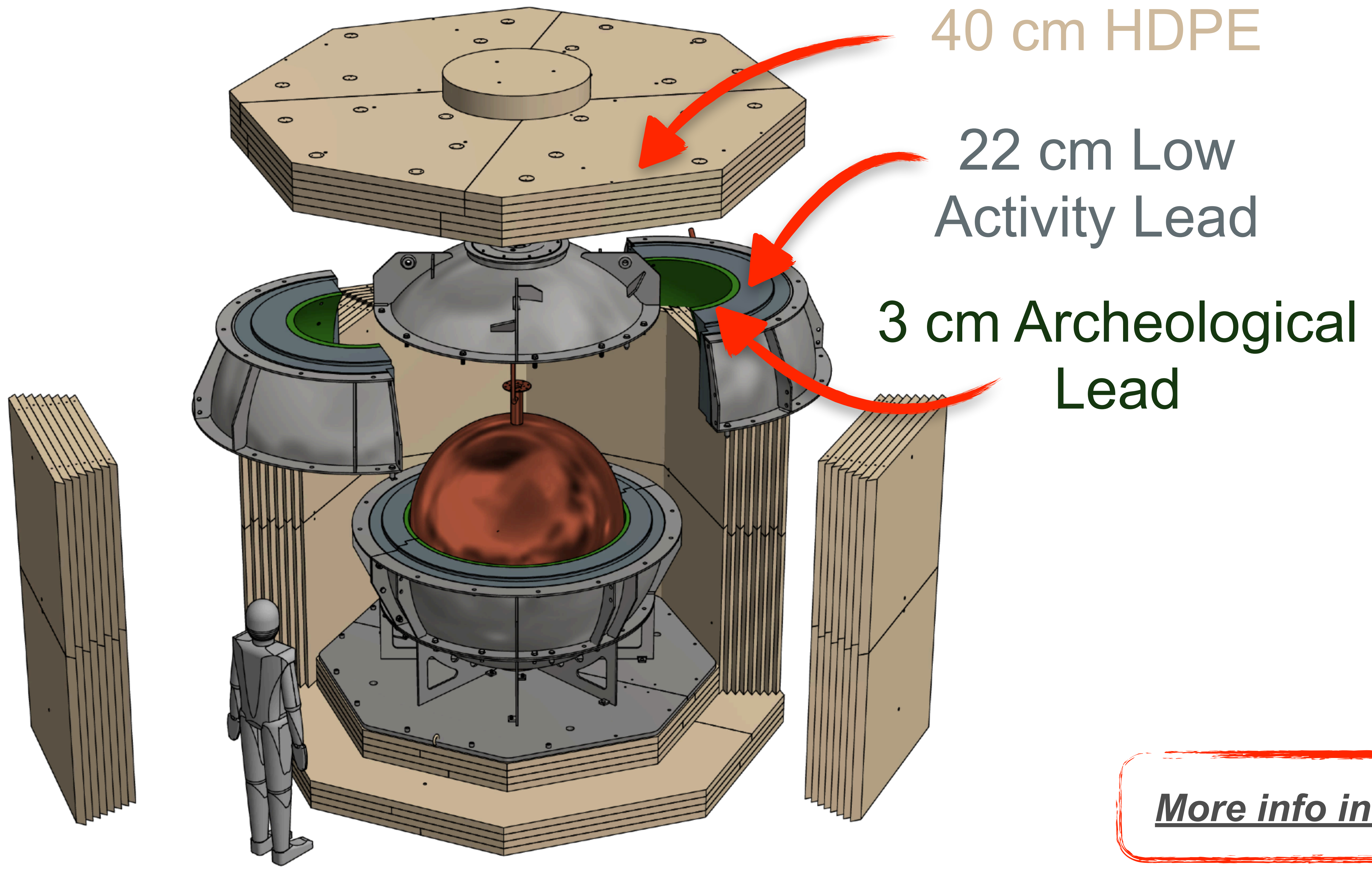
In LSM



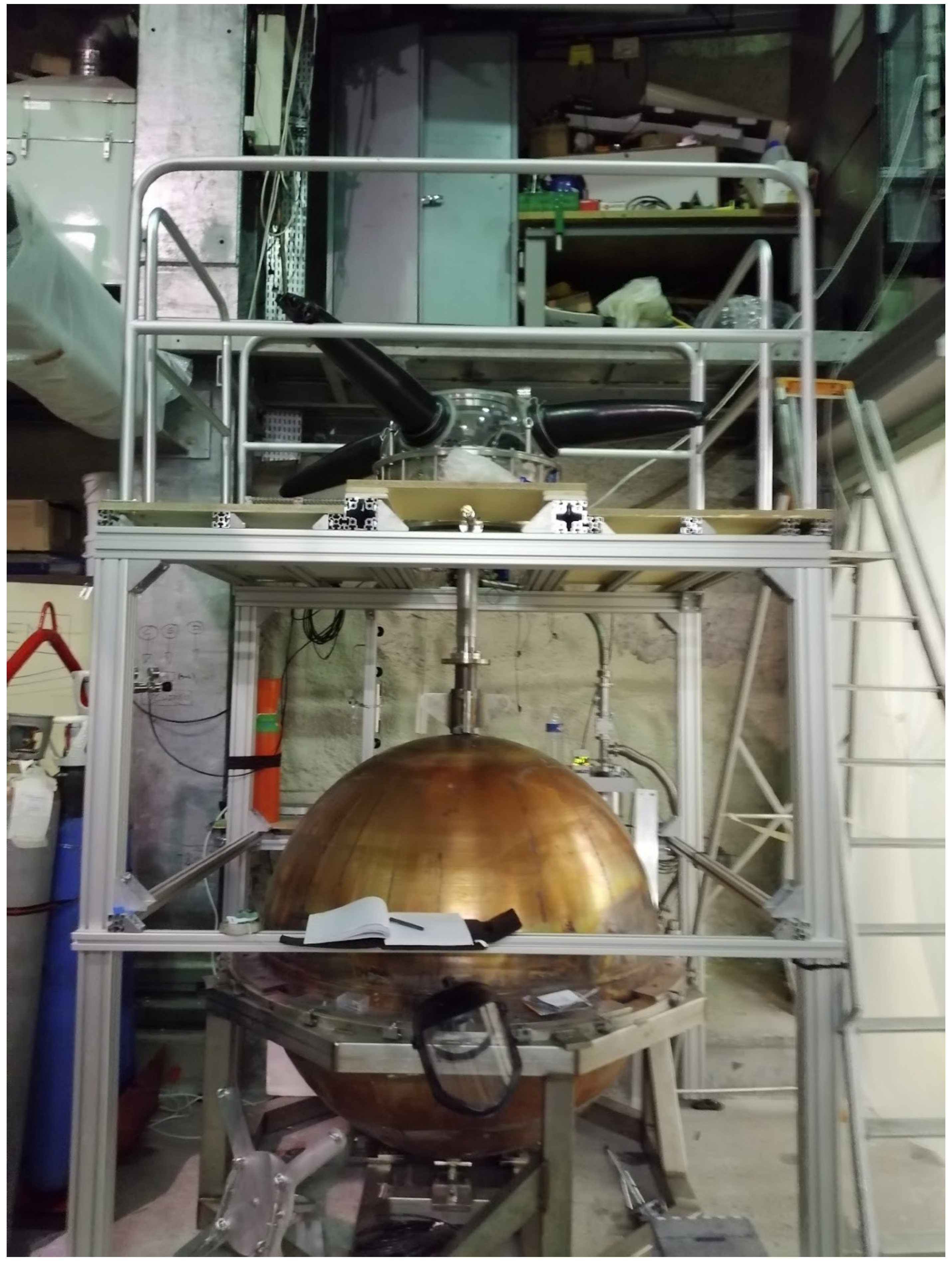
More info in recent article: arXiv 2205.15433

SNOGLOBE

- New ⌀**140 cm detector**
- **4N** (99.99% pure) Aurubis copper
- Constructed and tested in LSM, France
- Now being commissioned in SNOLAB, Canada

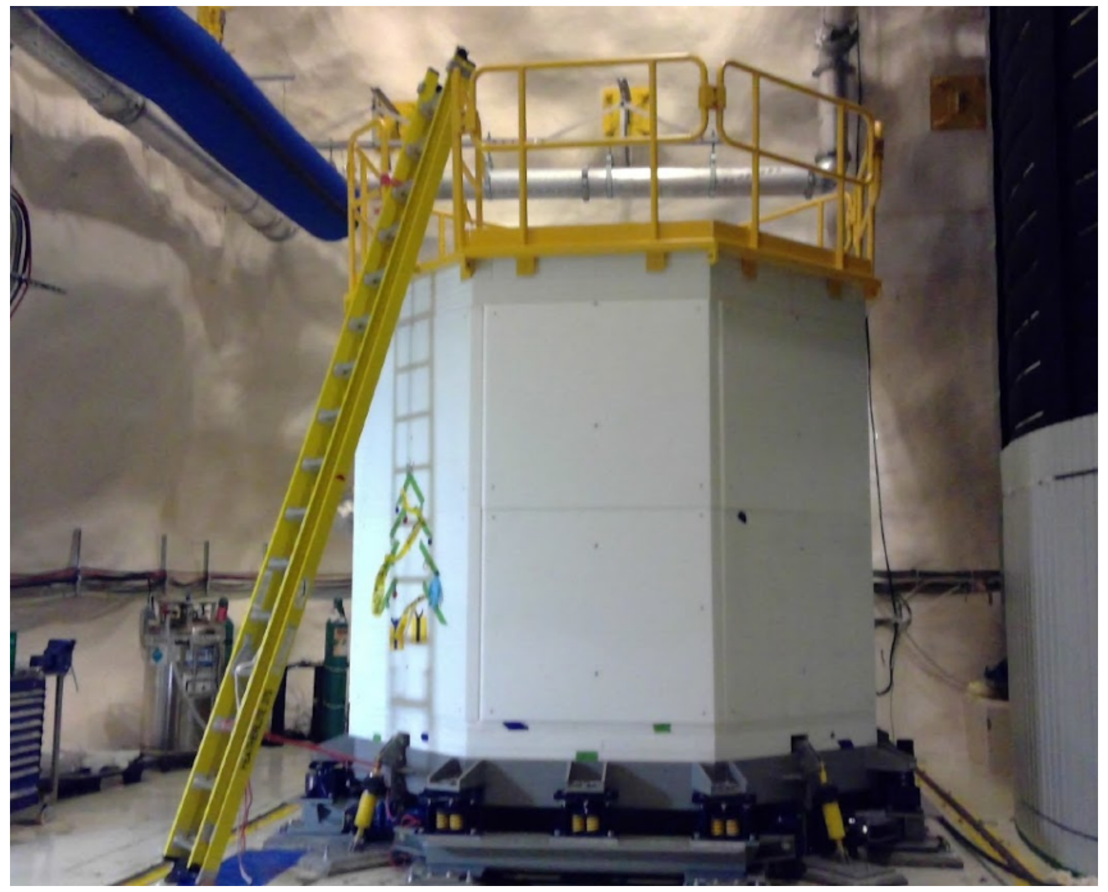


In LSM



Location in SNOLAB

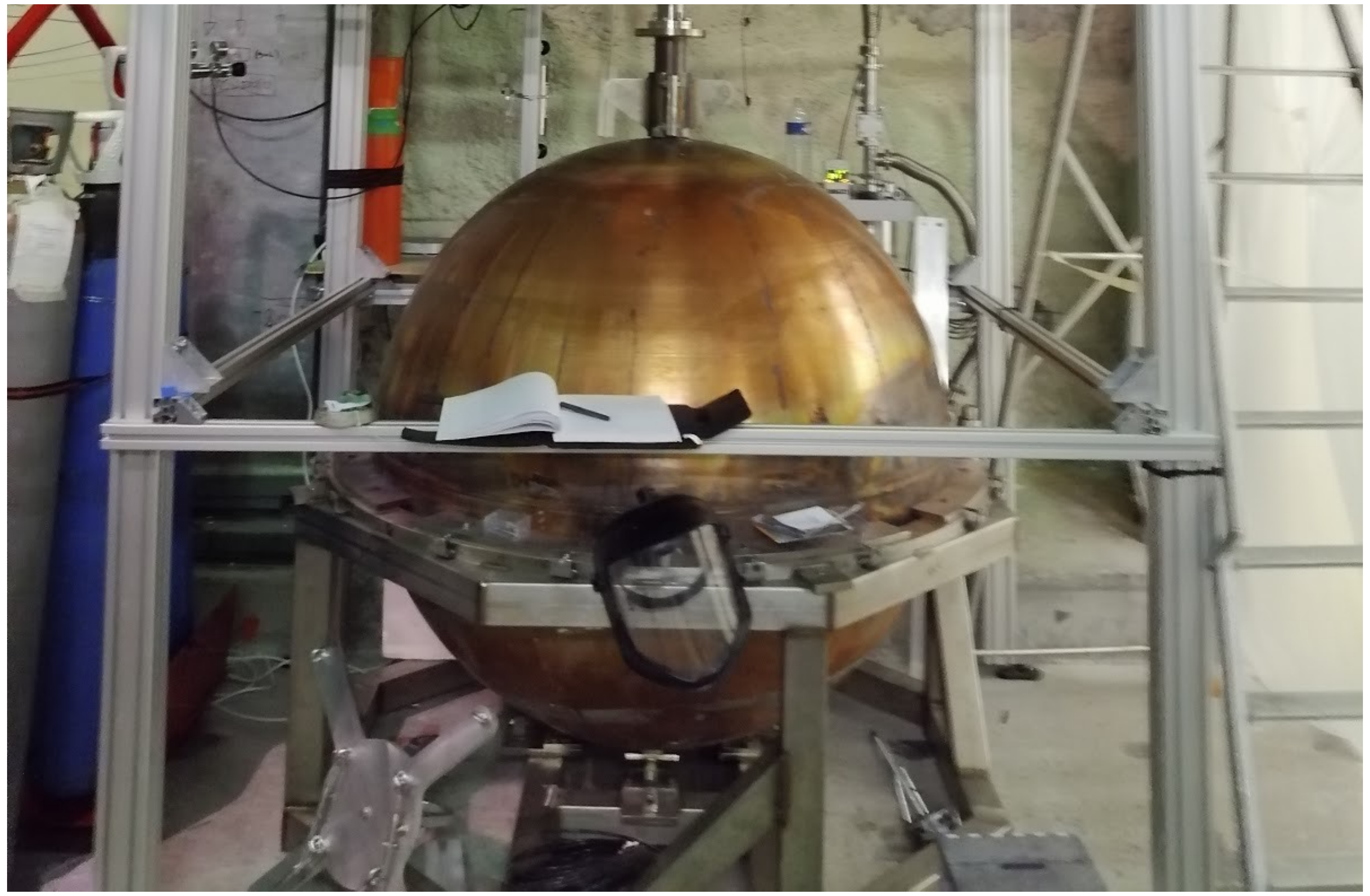
Installed in SNOLAB
Dec 2020



More info in recent article: arXiv 2205.15433

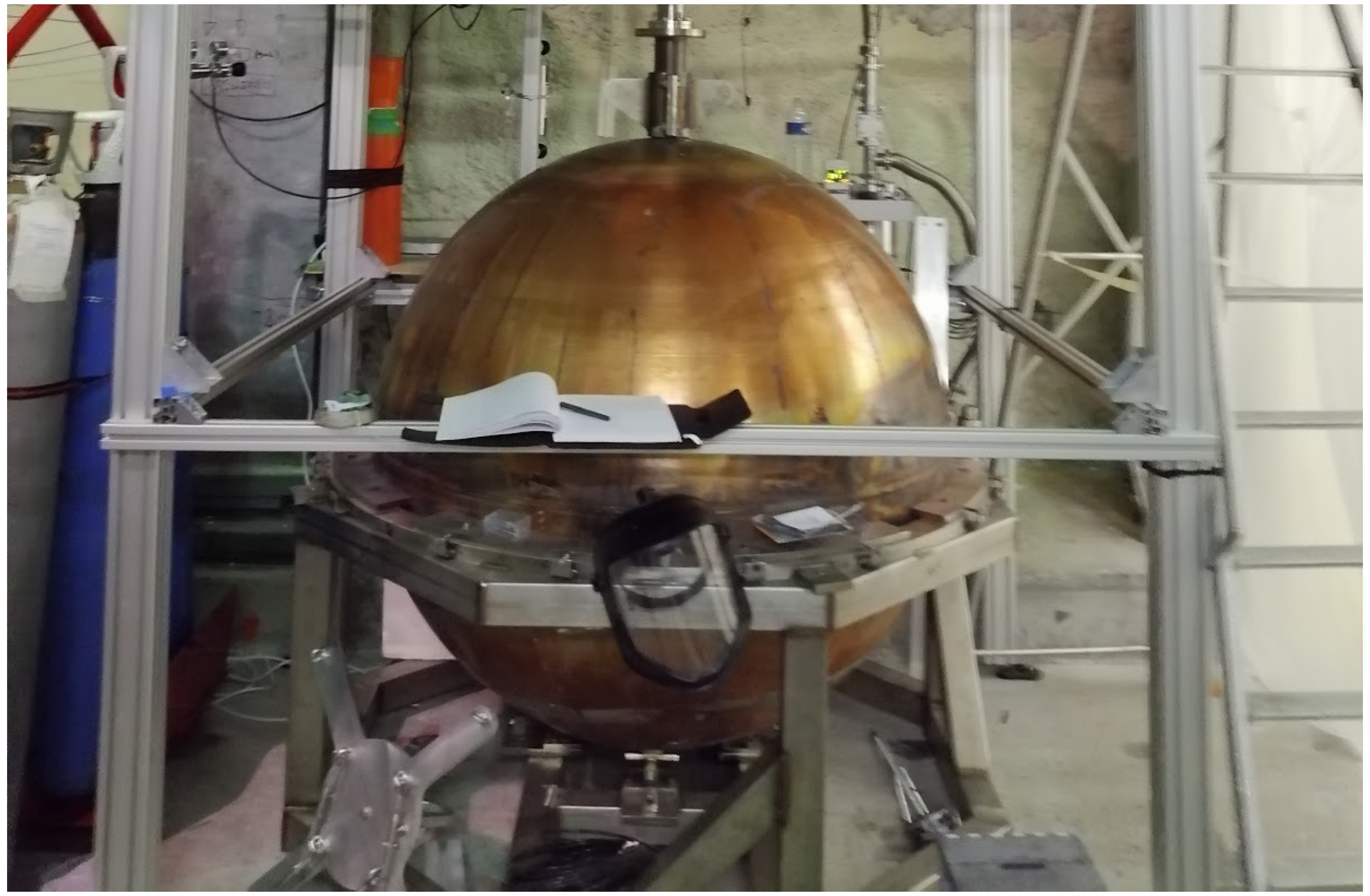
SNOGLOBE in LSM

- Constructed and first operated in LSM
- Initial commissioning data taking in LSM
  - **UV Laser and ^{37}Ar calibration systems**
  - **Multi-anode sensor - ACHINOS**
- Temporary lead + water shielding installed end 2019
- **~10 days of commissioning data taken**
  - **135 mbar of CH_4 (~100g)**



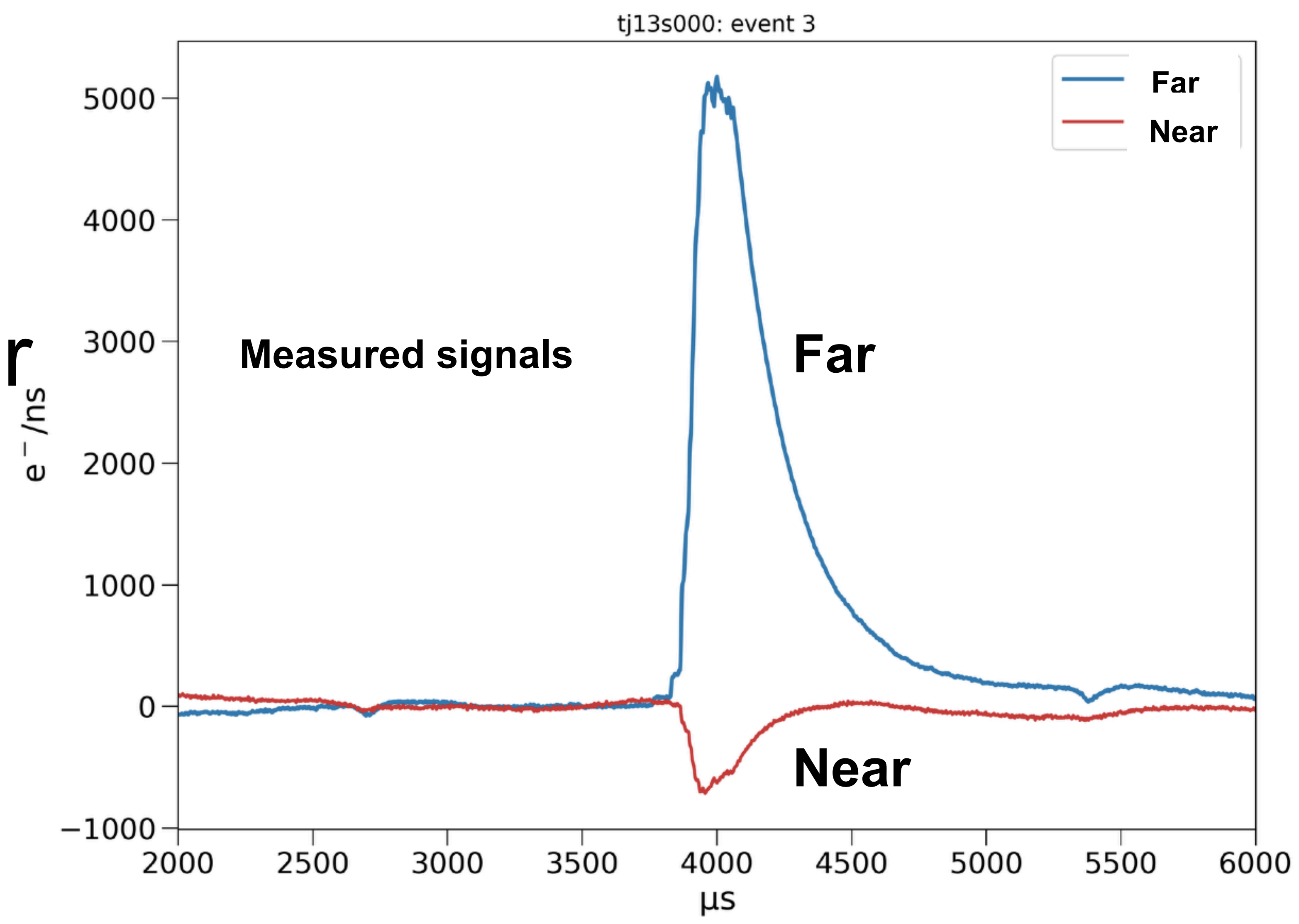
SNOGLOBE in LSM

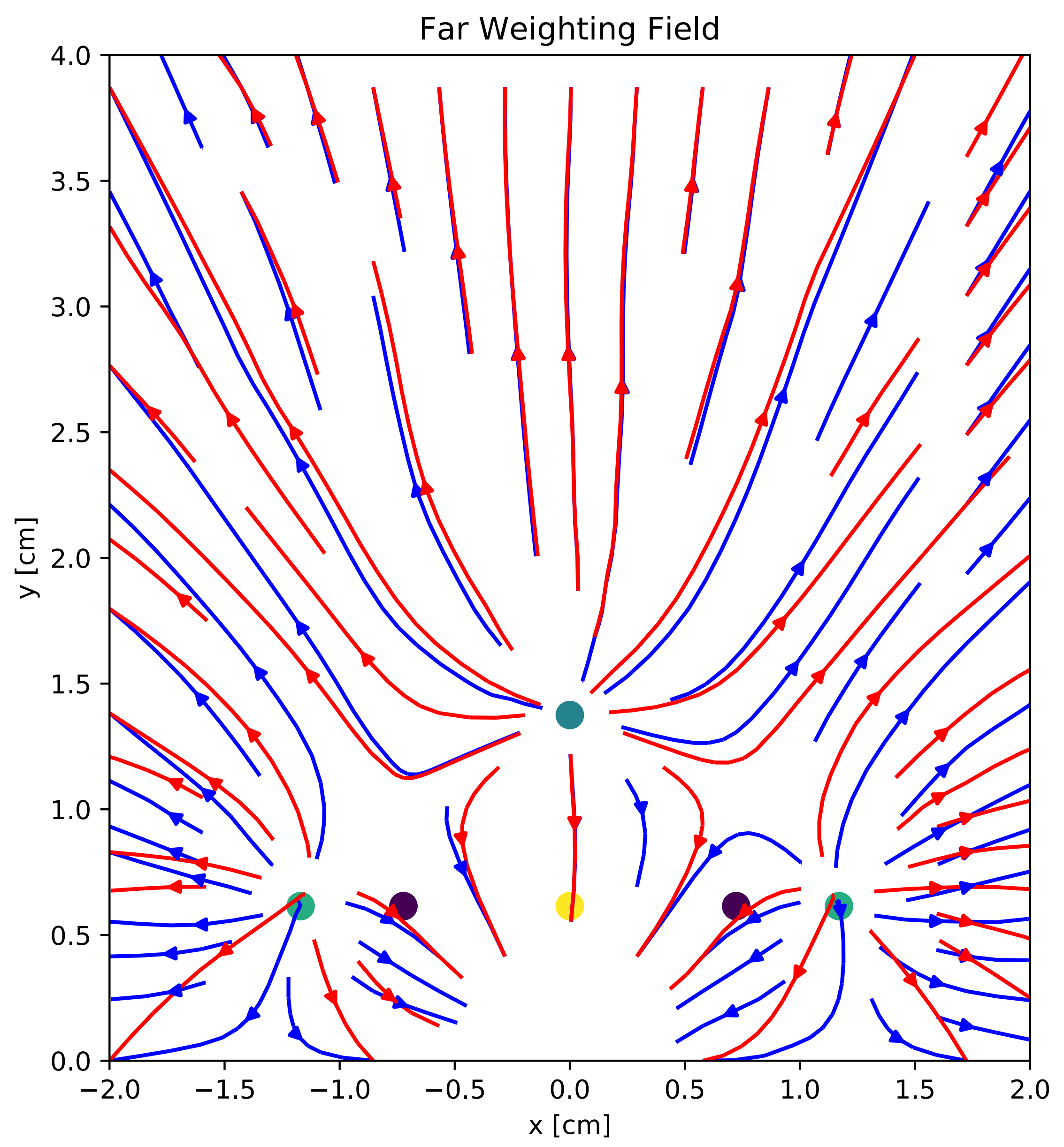
- Constructed and first operated in LSM
- Initial commissioning data taking in LSM
  - **UV Laser and ^{37}Ar calibration systems**
  - **Multi-anode sensor - ACHINOS**
- Temporary lead + water shielding installed end 2019
- **~10 days of commissioning data taken**
  - **135 mbar of CH_4 (~100g)**

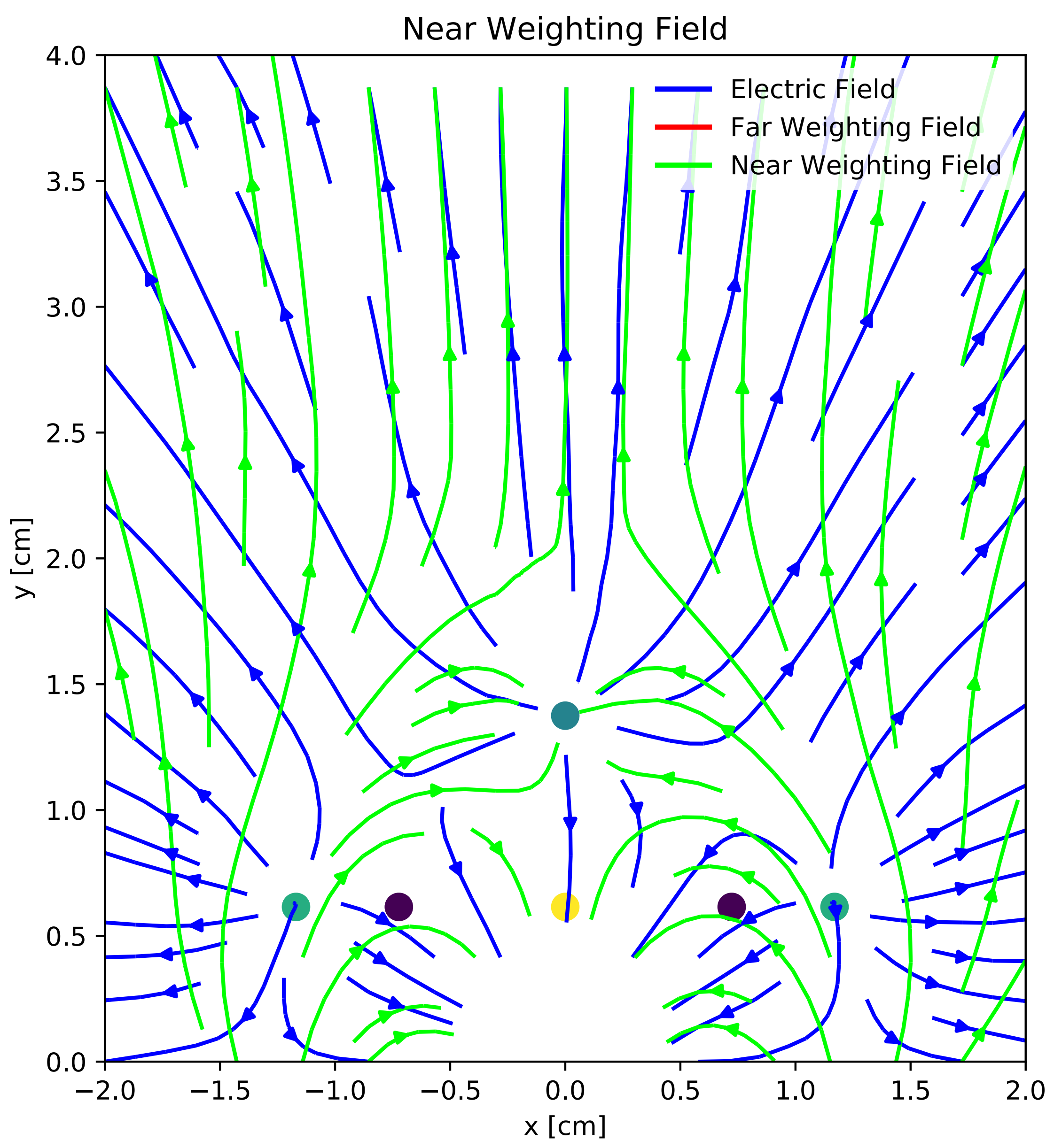


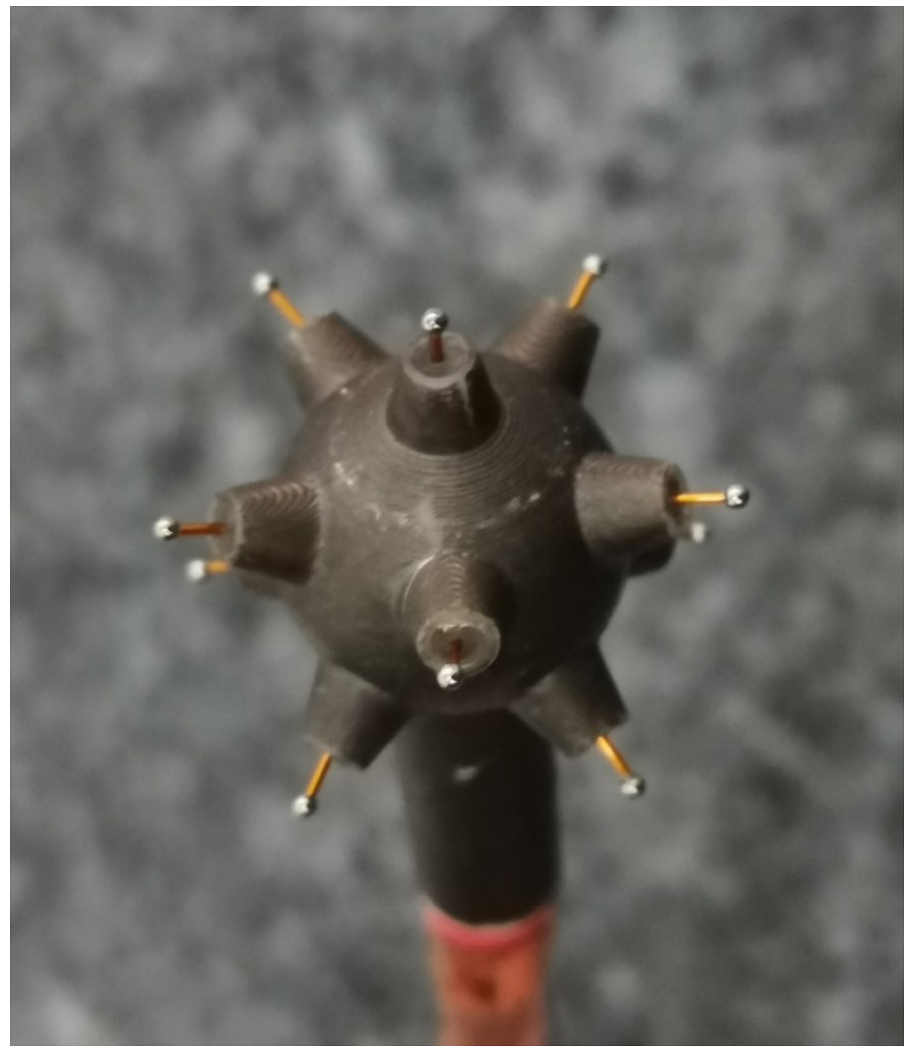
ACHINOS

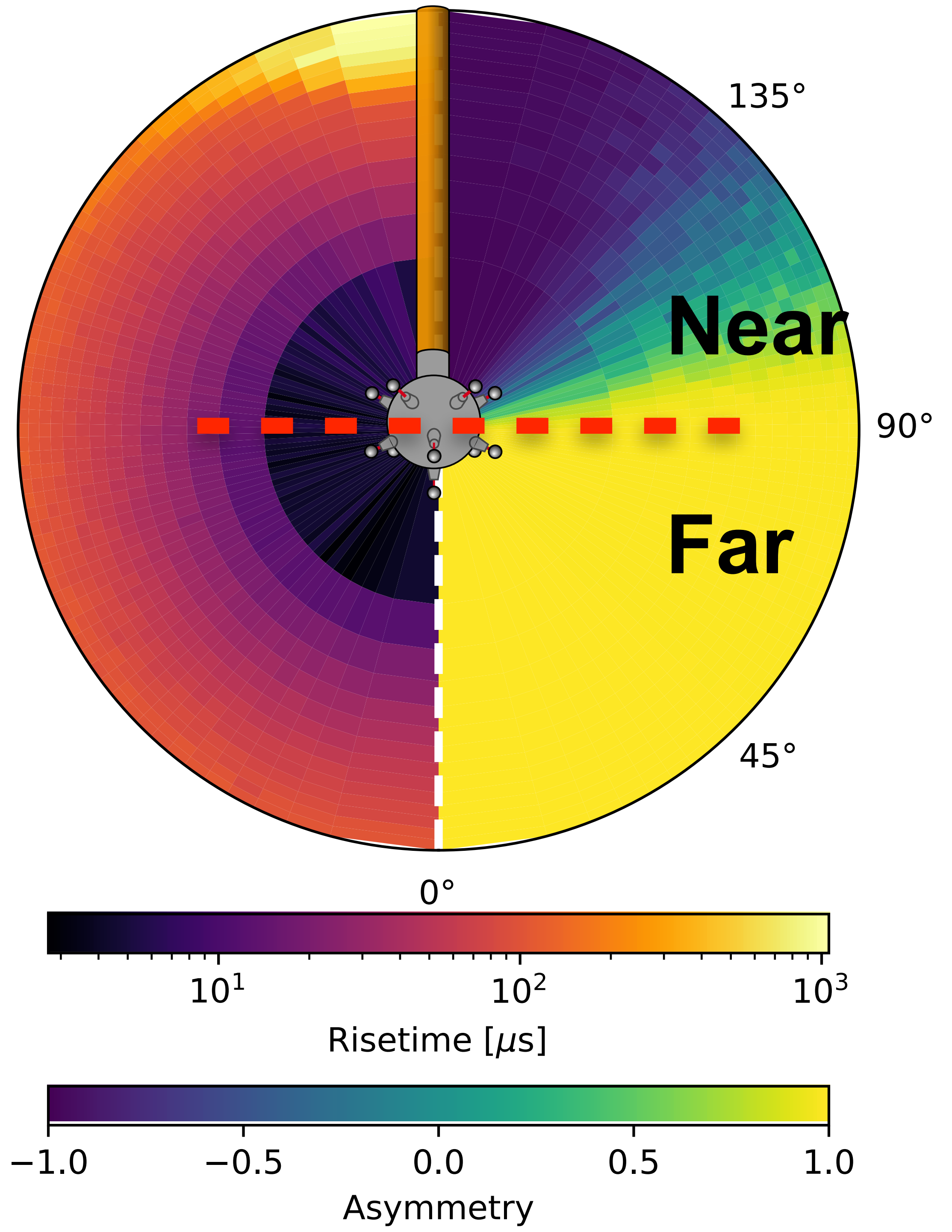
- Single anode: **gain and drift fields coupled**
- Idea: **Multiple anodes** located at same distance from centre of detector
- **Gain and drift decoupled**
  - **Drift field** determined by **collective field of all anodes**
  - **Gain** determined by **individual anode**
- Currently, read out as 2-channels, near and far
- Observe the expected induced signal on other channel when electrons arrive exclusively to other





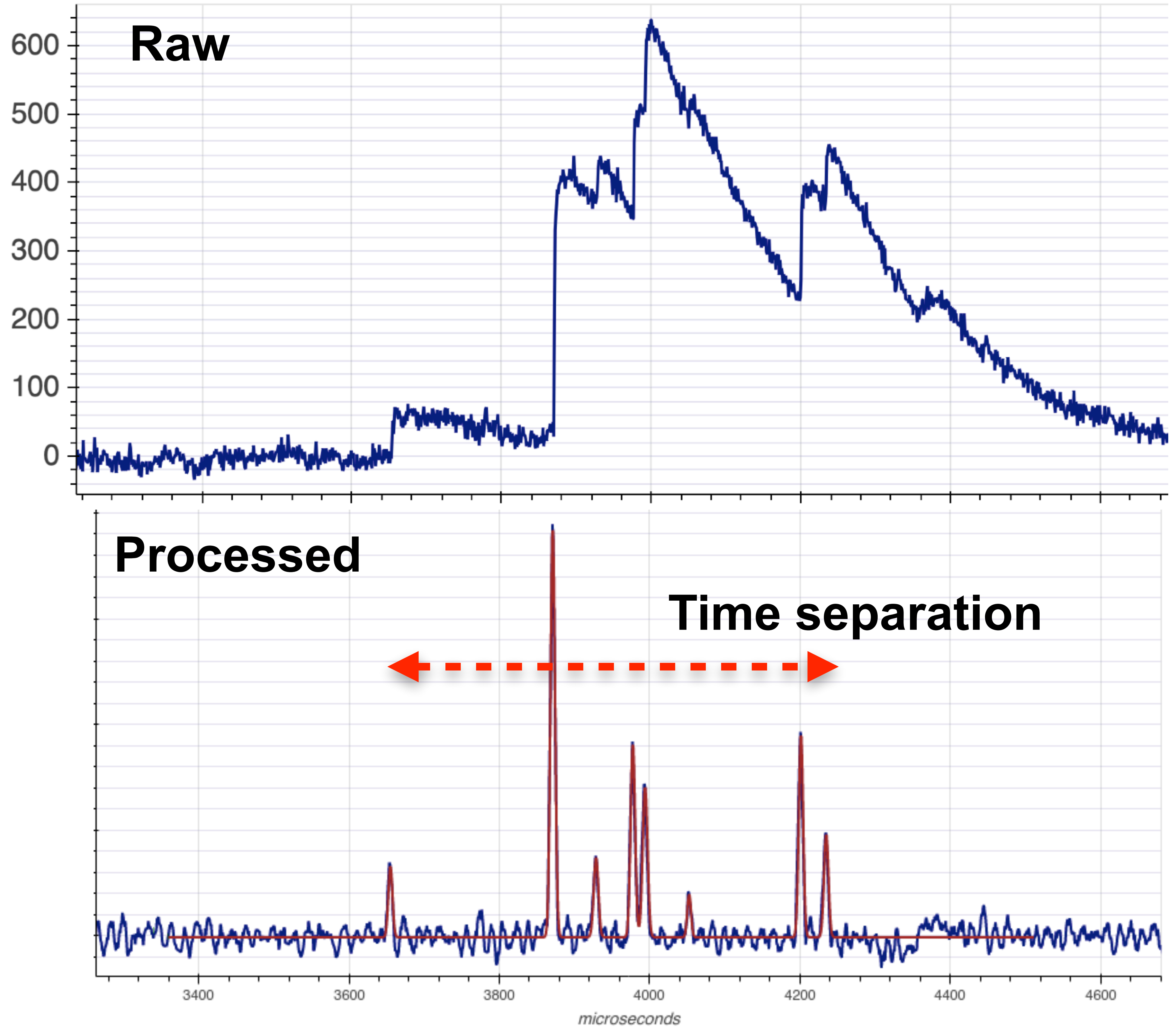


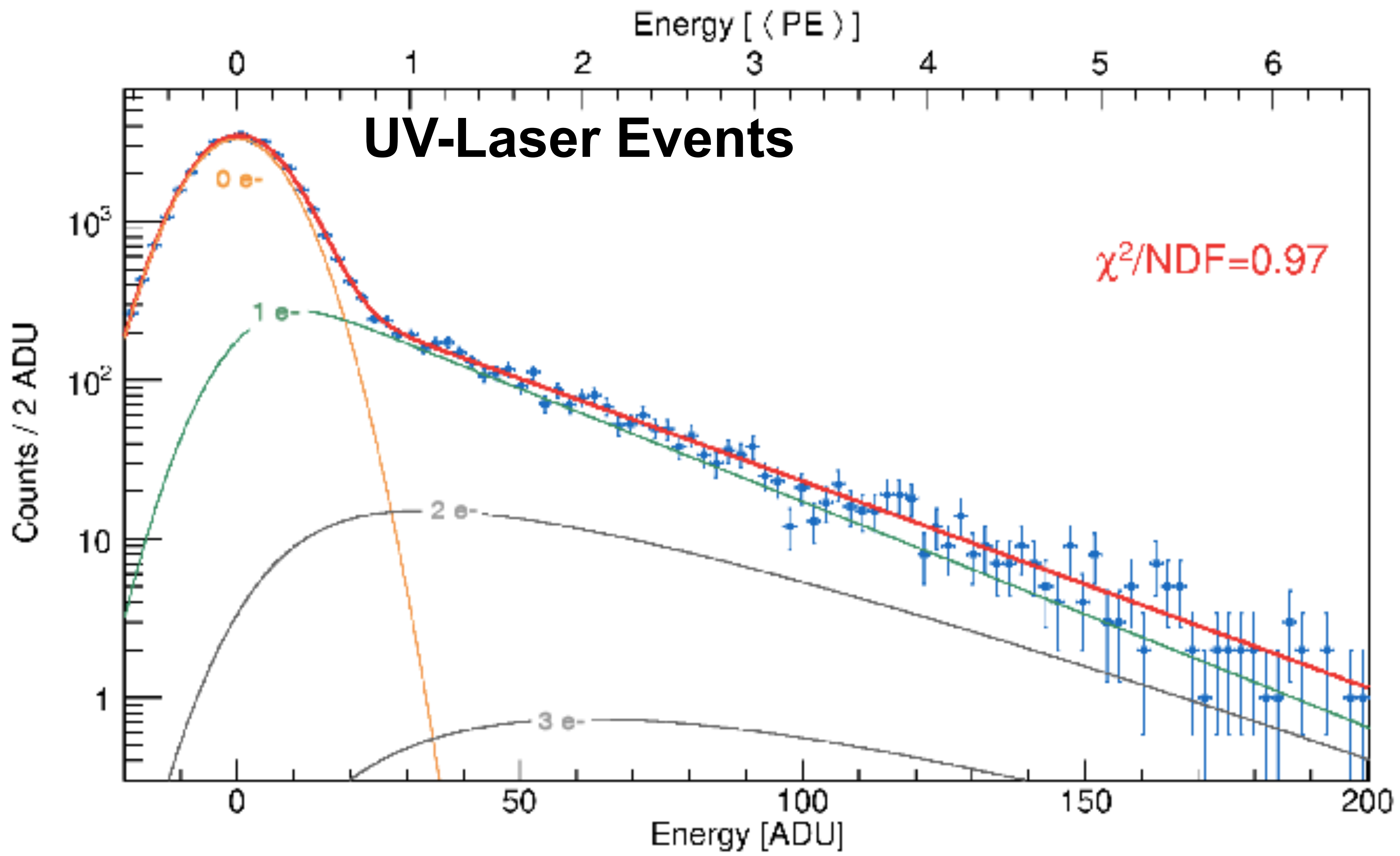




Electron Counting

- After pulse treatment, resolve primary electrons
  - Diffusion $\mathcal{O}(100\ \mu s)$ in commissioning data
  - If >1e, **time separation** surface/volume discrimination

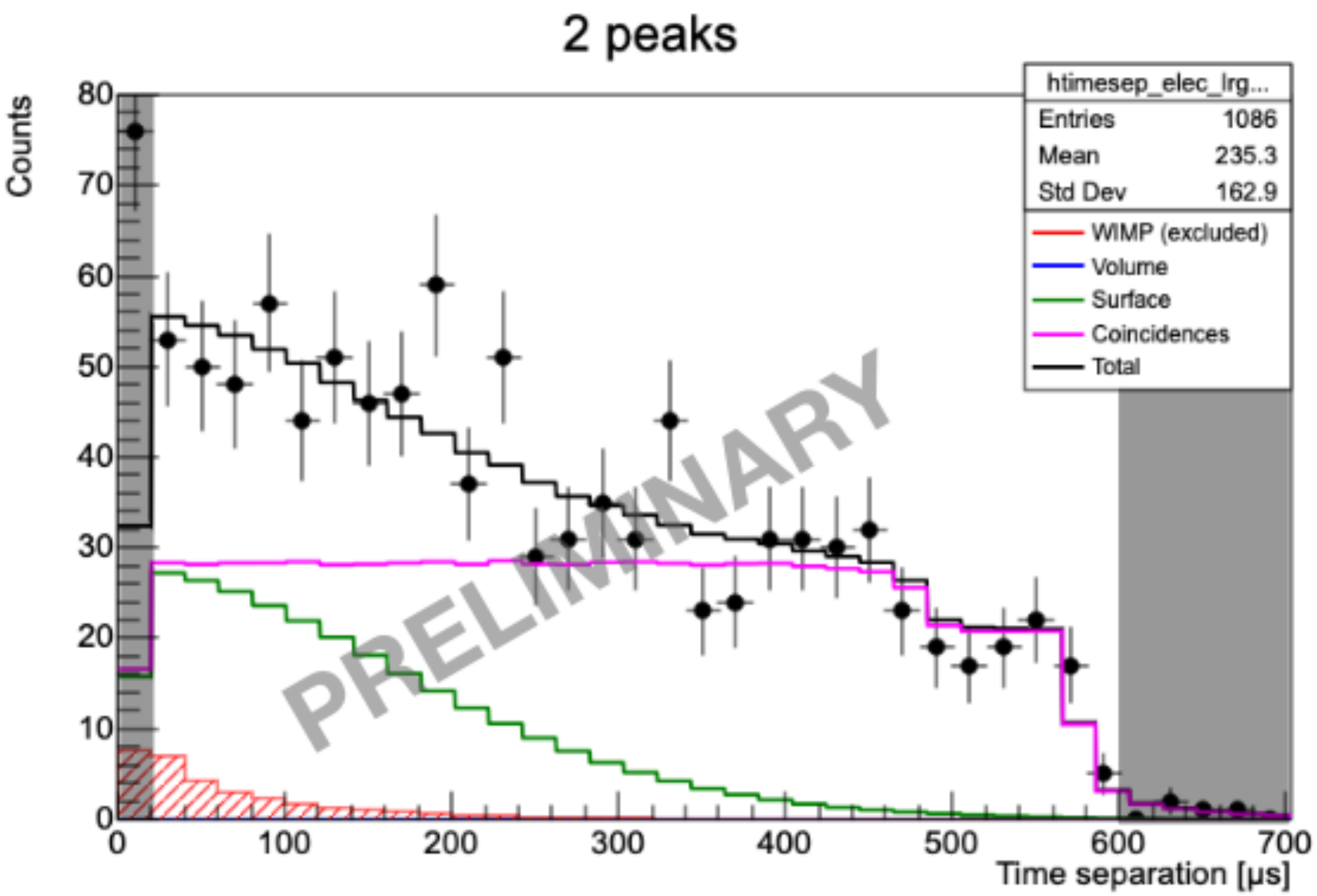


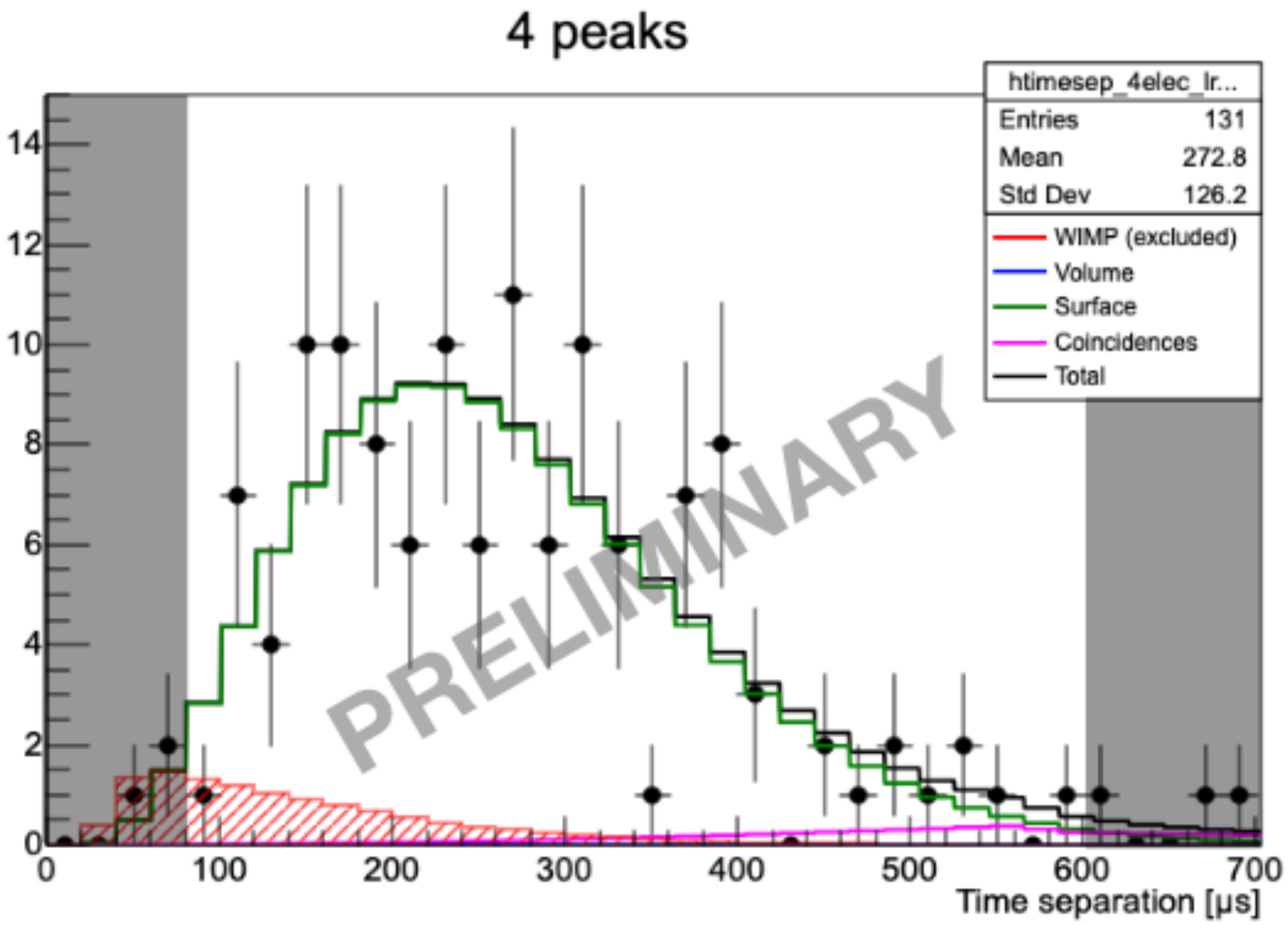


- **UV 231 nm laser** for continuous detector monitoring
  - Drift time, gain, efficiencies etc.
- ^{37}**Ar** at end of data taking
  - Gain measurements
  - W-value and Fano
  - Electron attachment

Commissioning Data

- Data divided into 2/3/4 peak
- Principle discriminating variable: time separation
  - Surface/volume and coincidence discrimination
- Only test data analysed so far: ~30% data
  - Remaining data is blind
- No significant DM signal observed

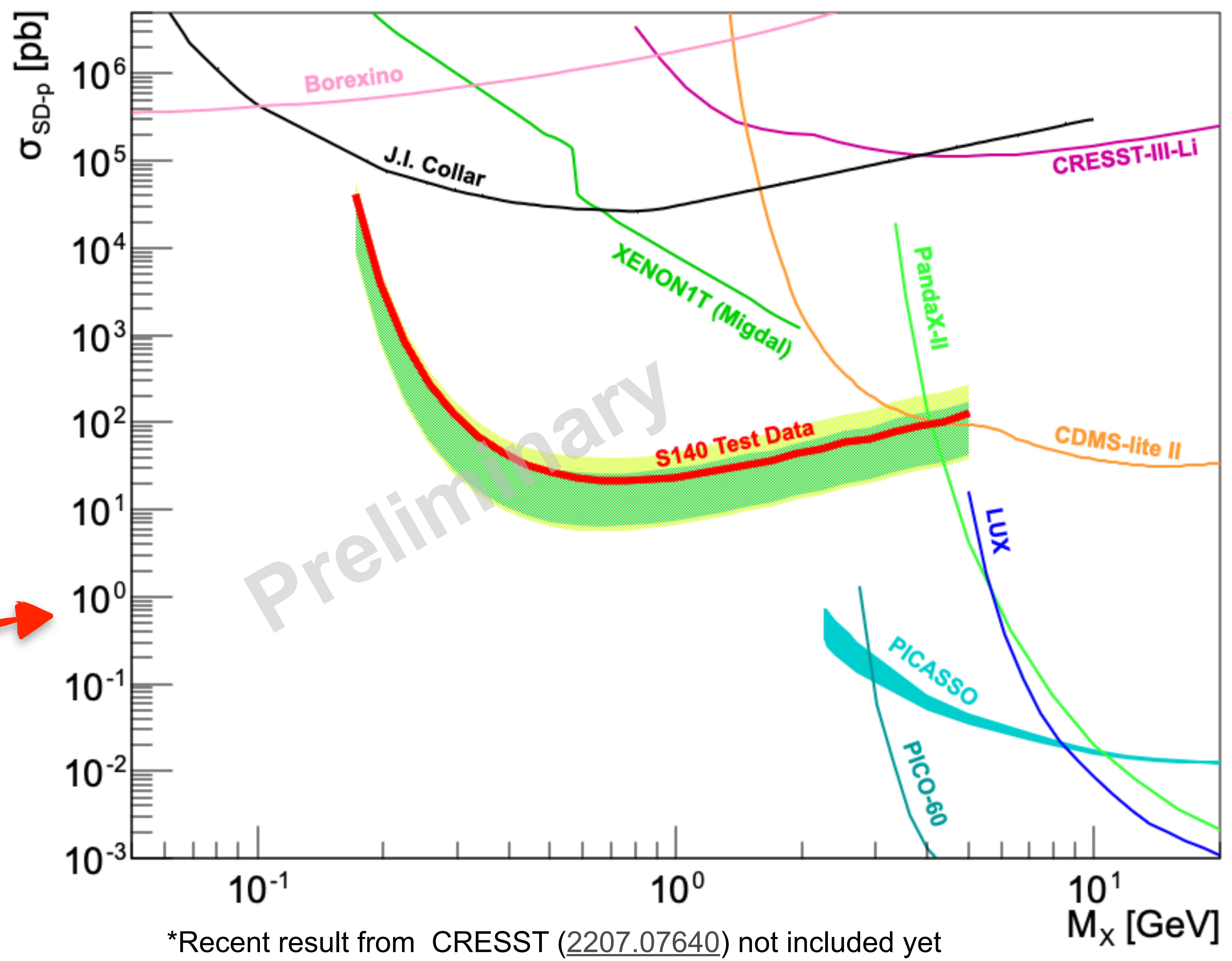




LSM Physics Result

- Results with 0.12 kg·days test data
- Combination of W-value and Comimac QF used
  - Conservative logarithmic extrapolation
- Profile likelihood ratio method used to calculate 90% exclusion limit
- Full results with blind data expected within weeks - **potential for best constraints on SD-p DM interactions below 1 GeV!**

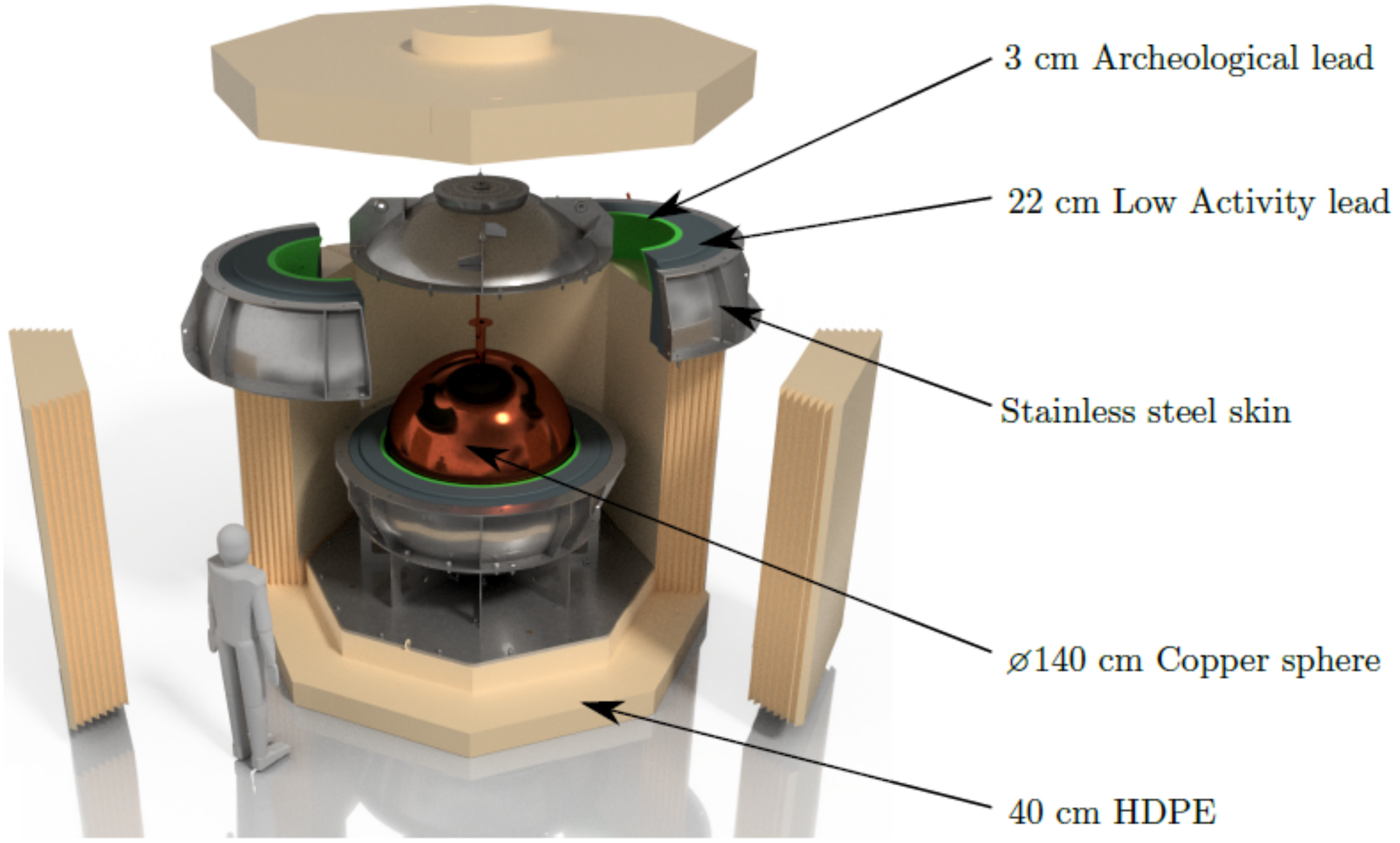
New Result!

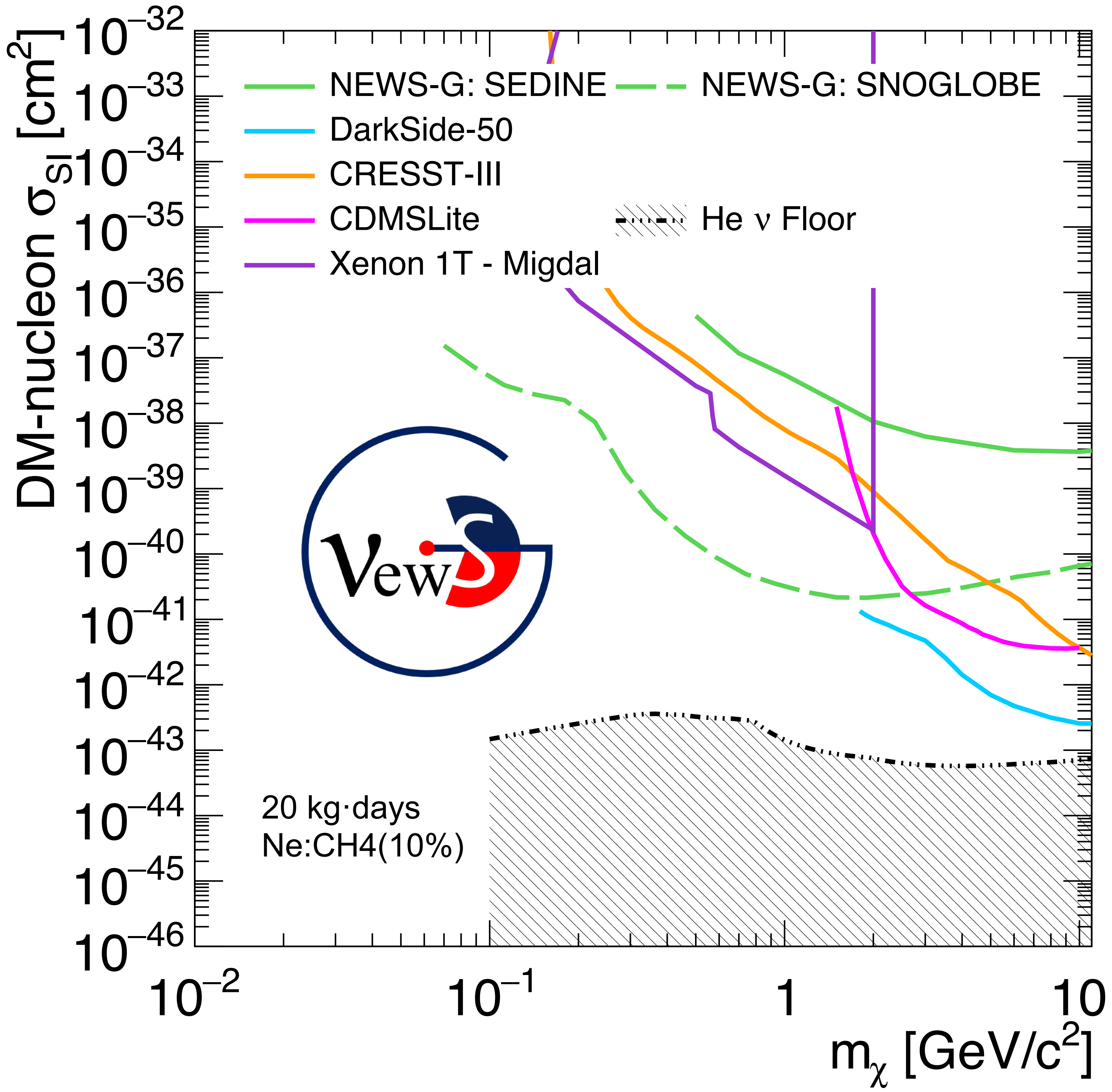


*Recent result from CRESST (2207.07640) not included yet

SNOGLOBE in SNOLAB

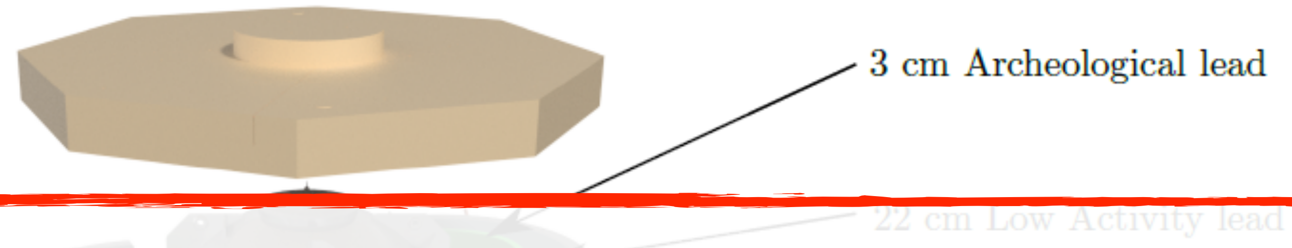
- Now in commissioning in SNOLAB



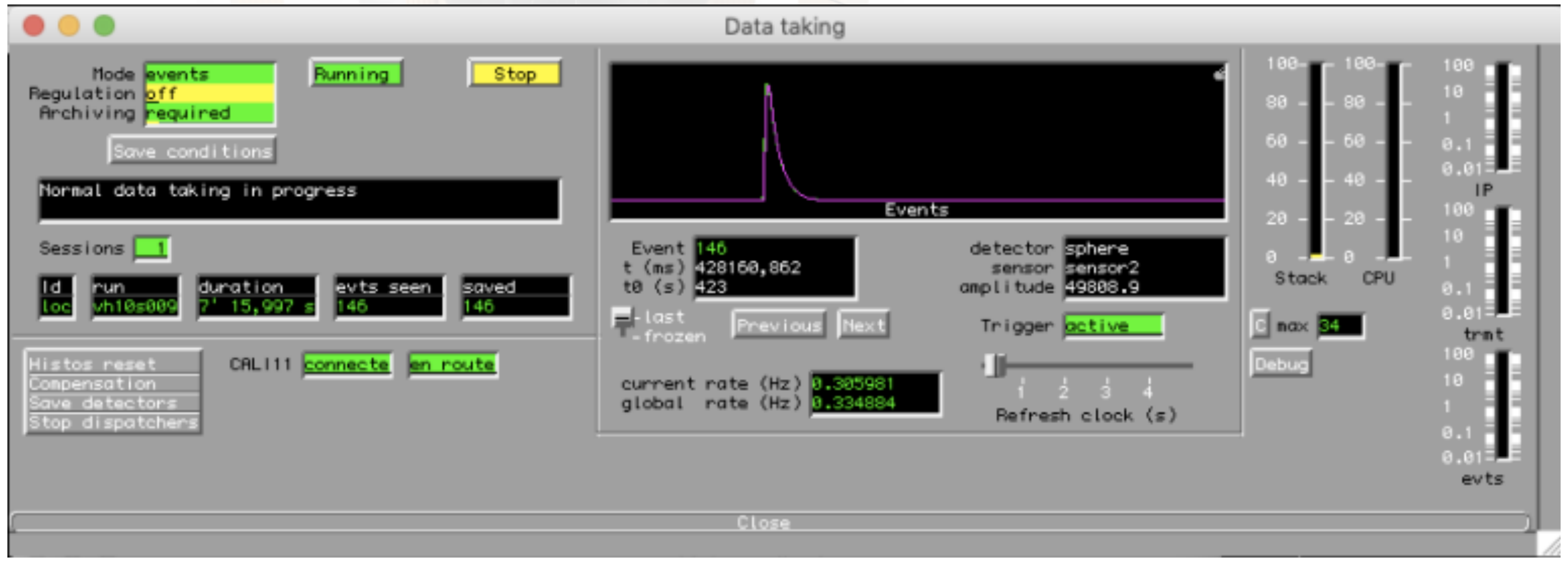


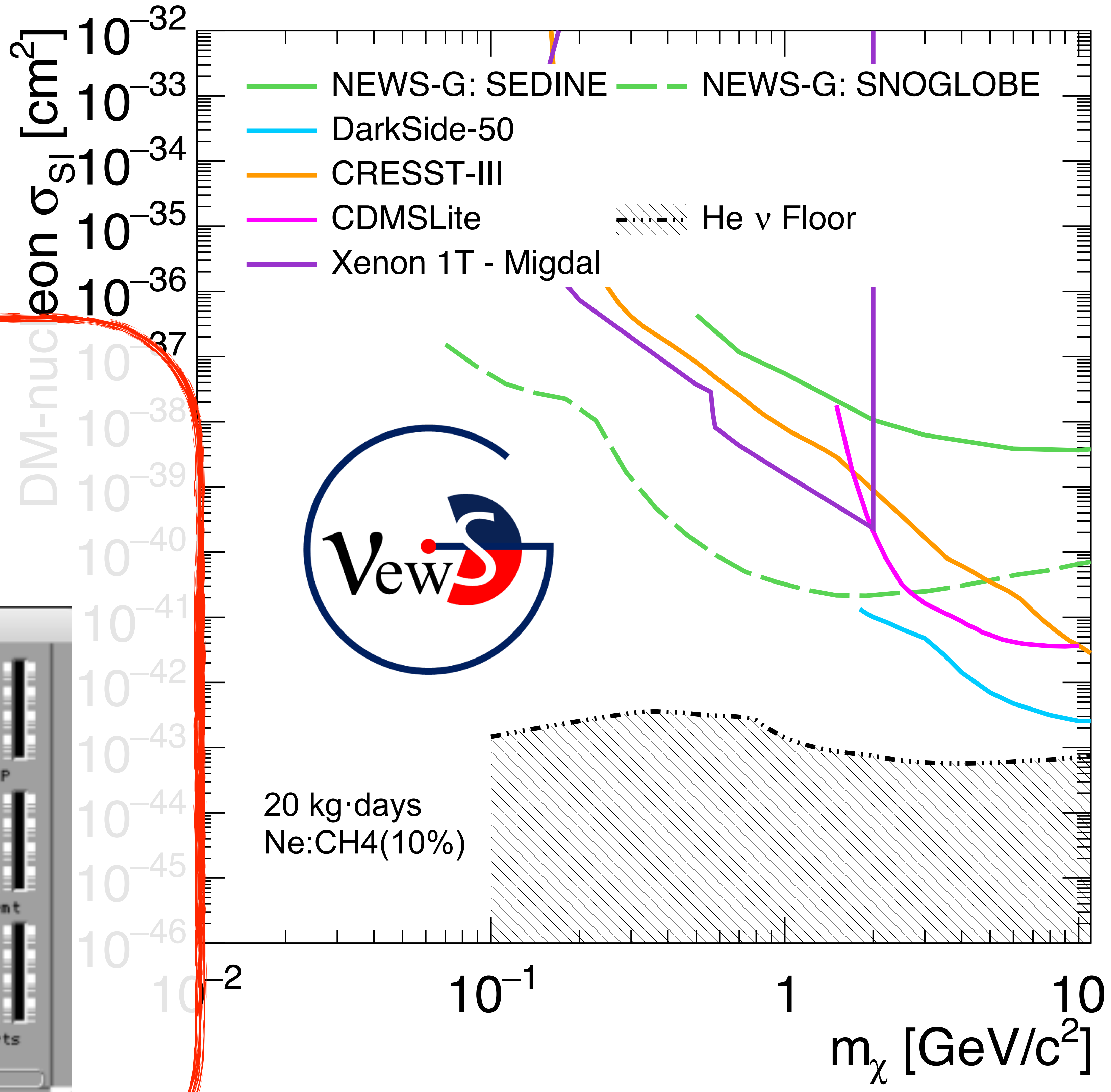
SNOGLOBE in SNOLAB

- Now in commissioning in SNOLAB

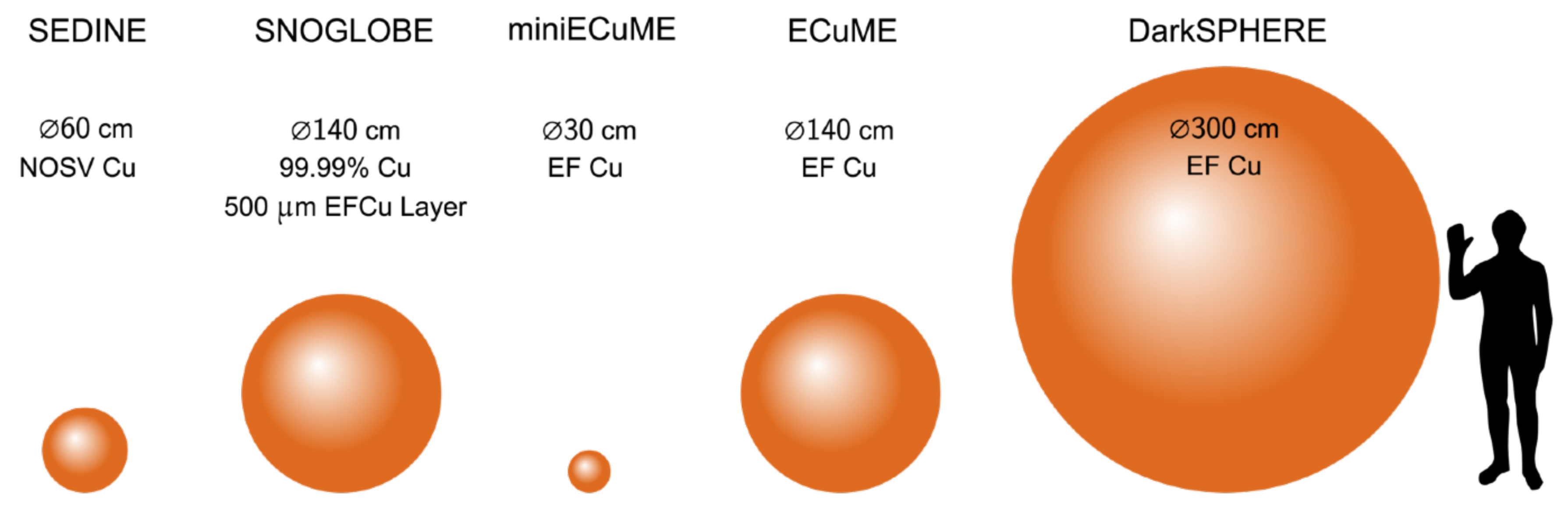


First signal in SNOLAB, summer 2021!

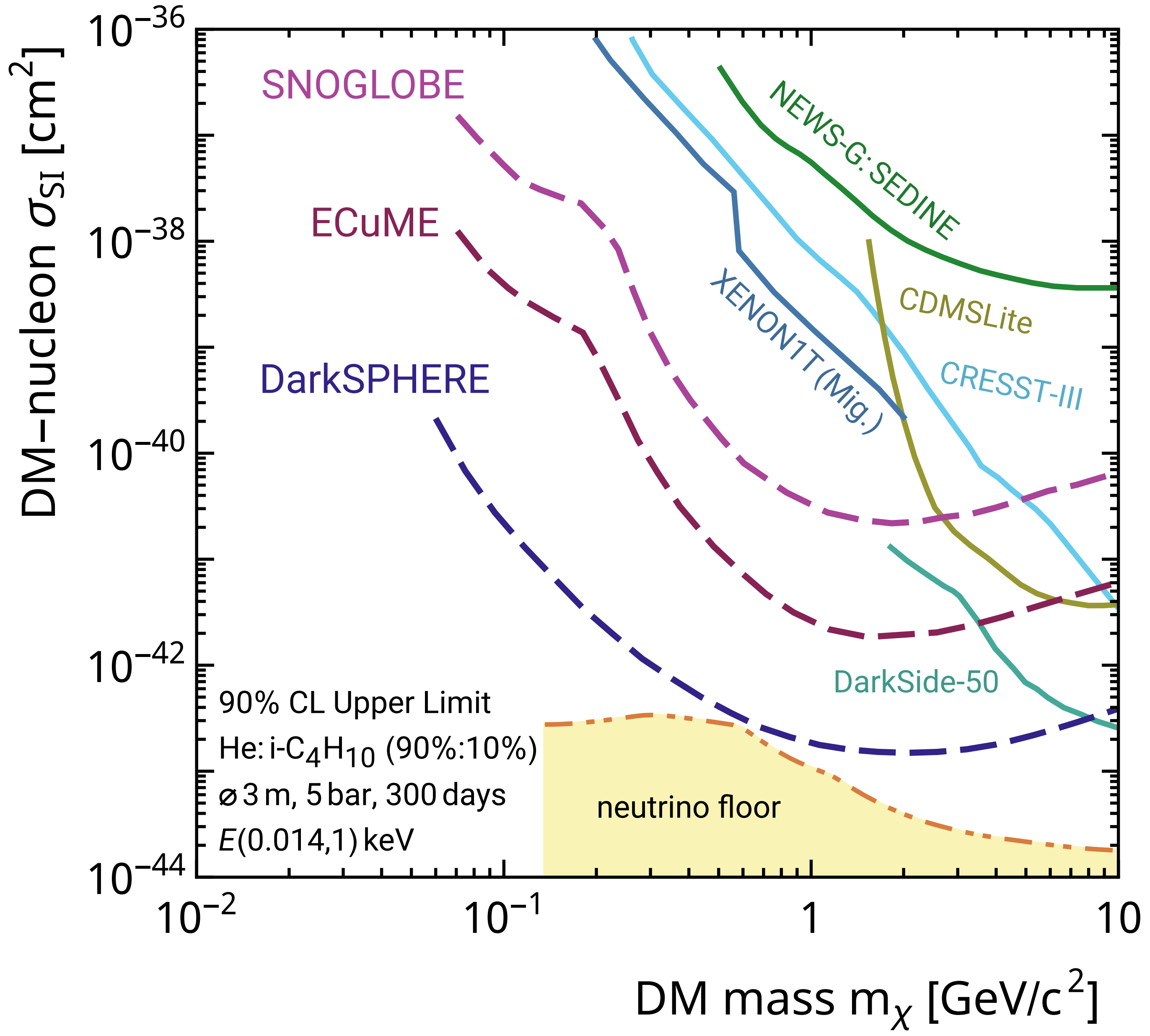


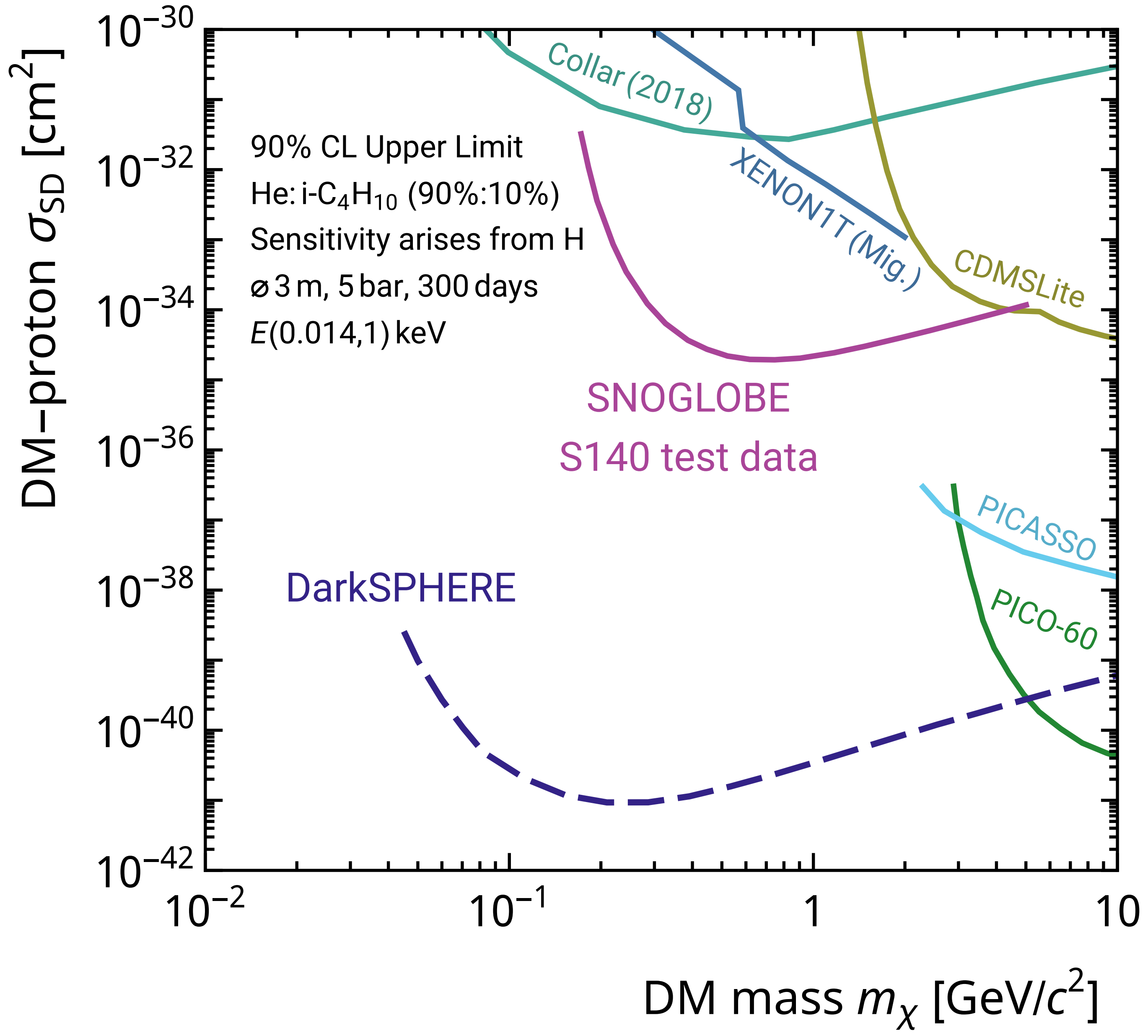


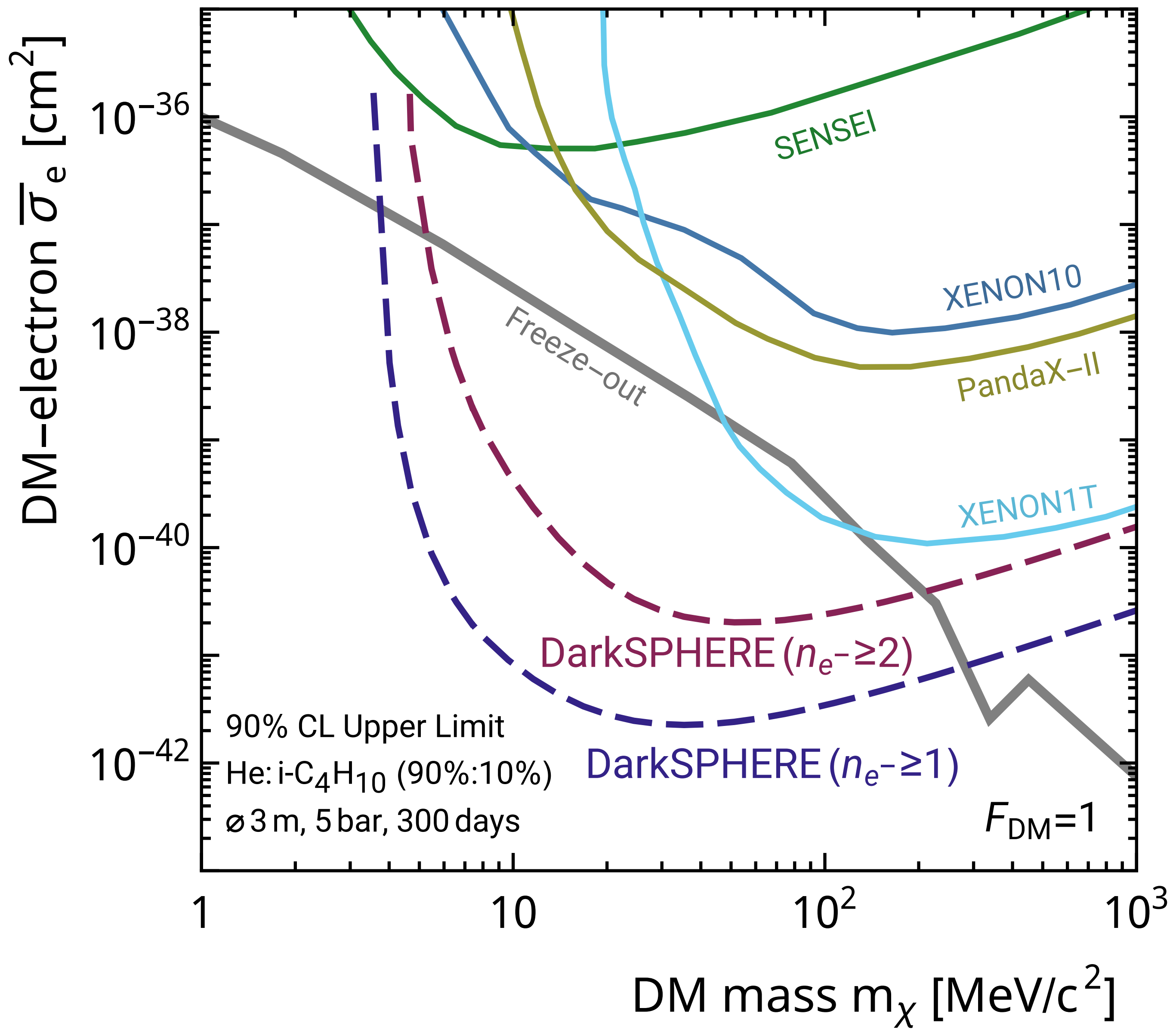
Future Detectors



- Dominant BG: Radioactivity and activation of copper
  - Idea: Use deep-underground, intact, electroformed detectors
- ECuME (SNOLAB): ⌀140cm SPC, to be installed in SNOGLOBE's shield
- Future: DarkSPHERE
  - ⌀3m SPC with water-based shielding to minimise BG from environment

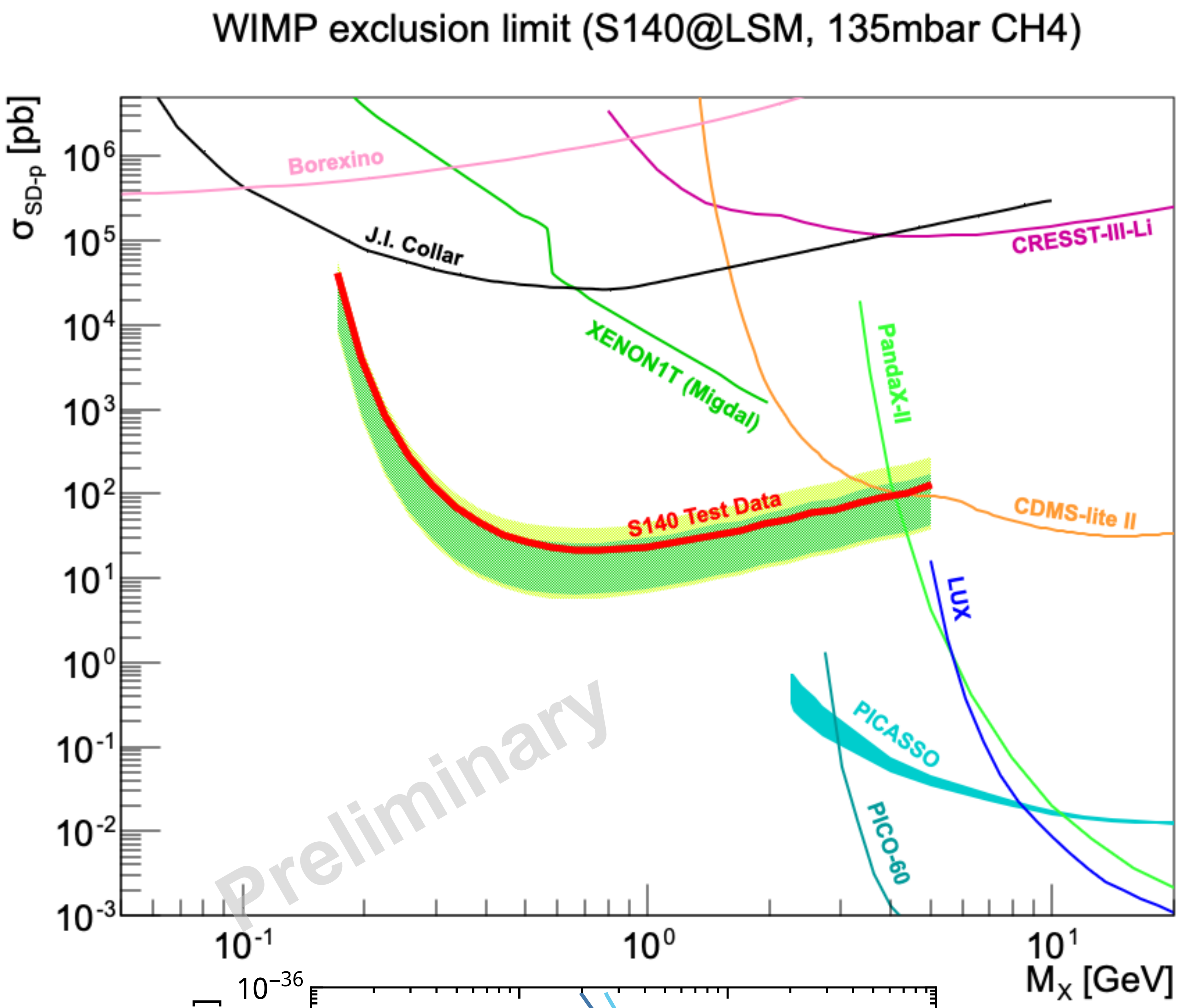


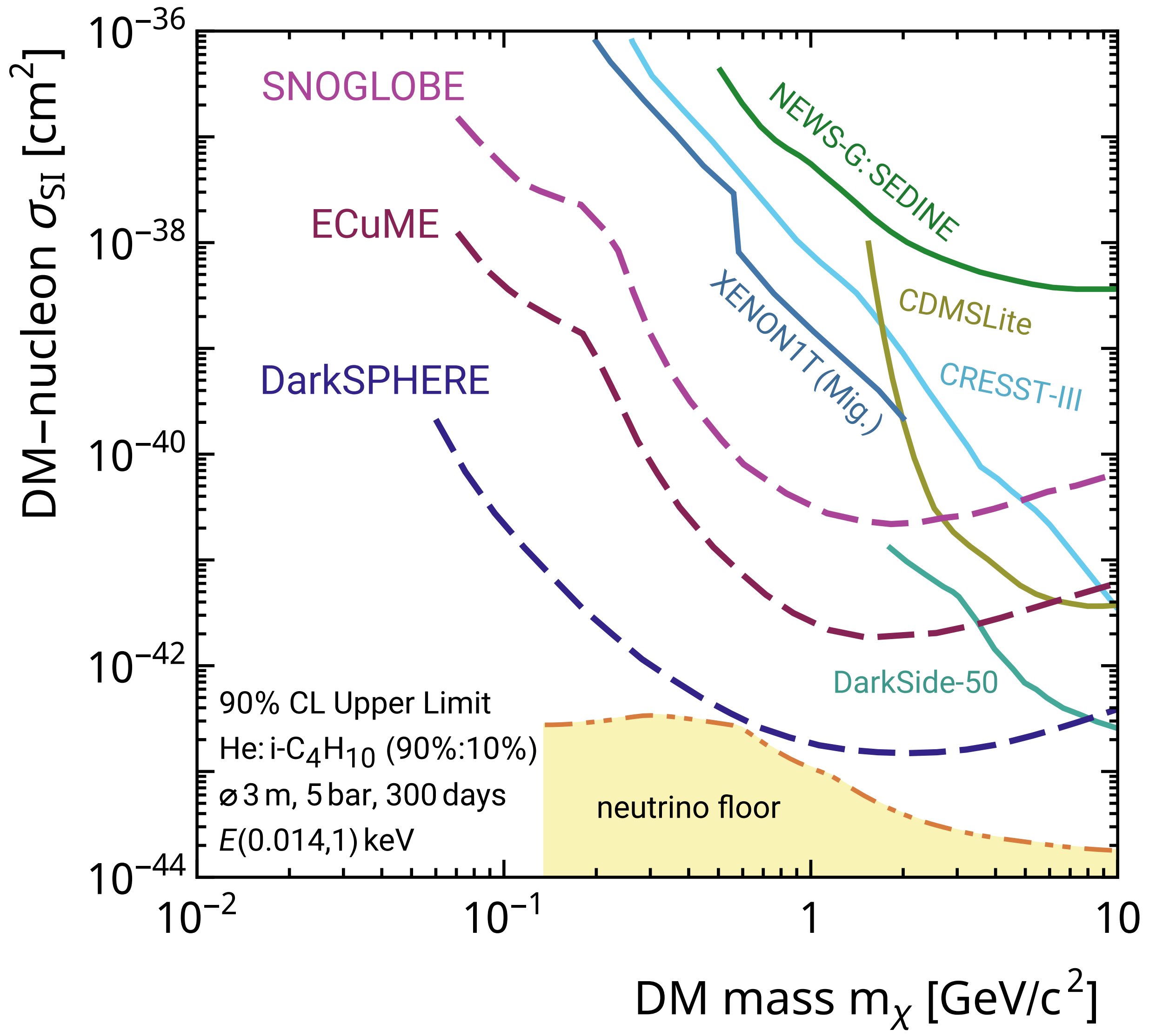




Summary

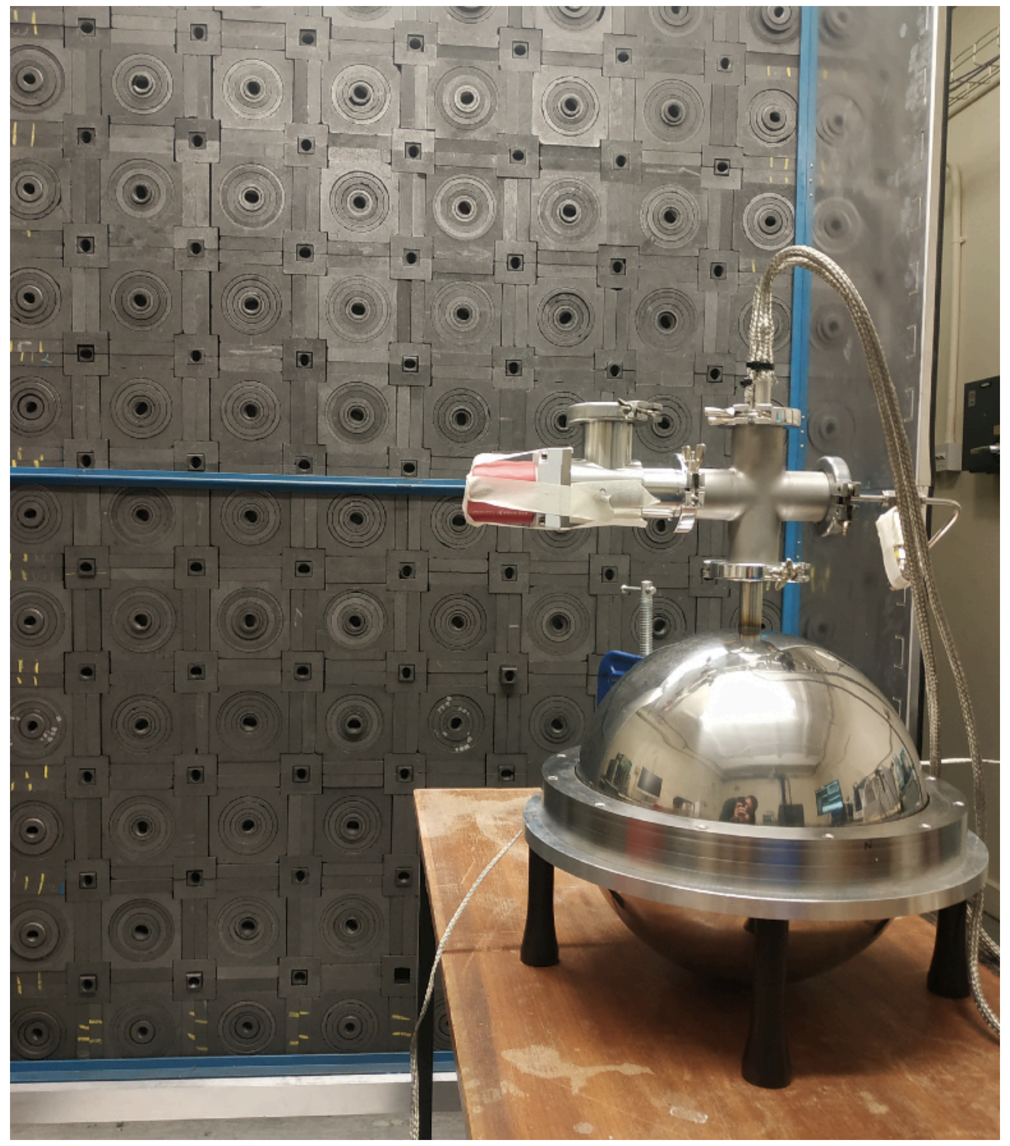
- SNOGLOBE: 140cm SPC
  - Commissioned and initially operated in LSM
- Commissioning data ~10 days with 135 mbar CH_4
- Only analysed ~30% data
  - expected to place world-leading limit on SD-p
- Data taking commencing in SNOLAB
- R&D an plans for future detectors ongoing



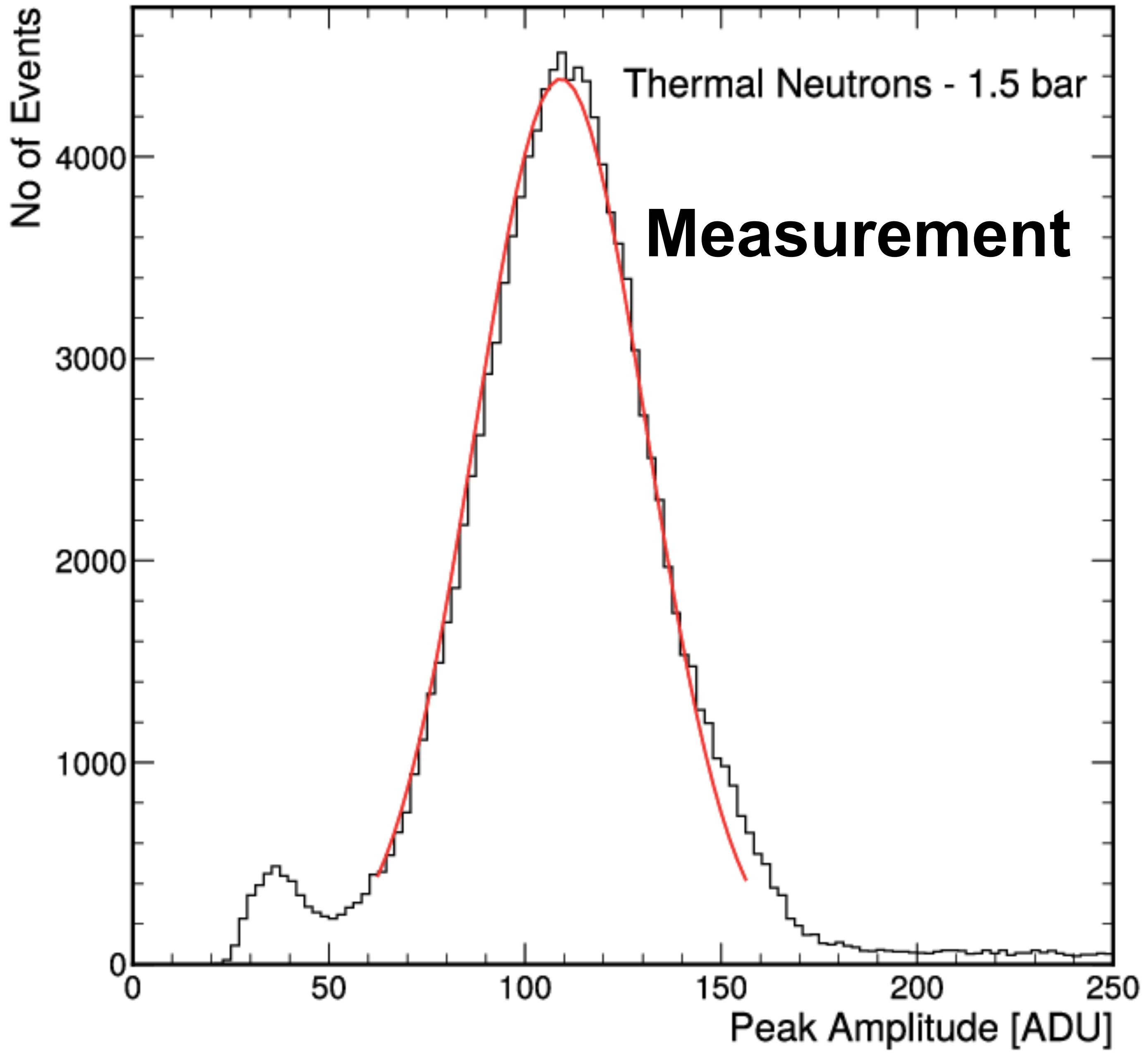


Neutron Measurements and ACHINOS

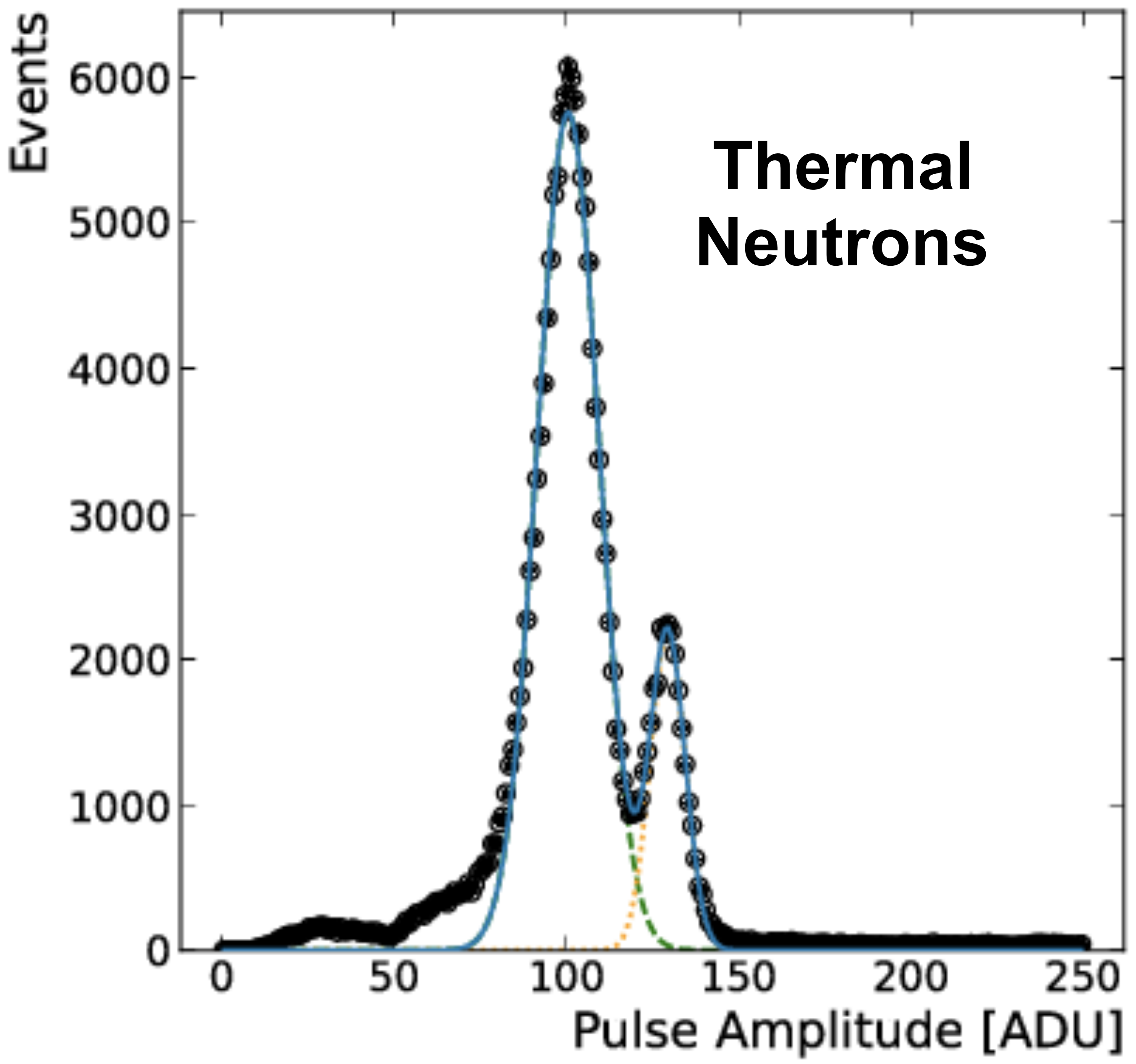
- N_2 filled SPC asa neutron detector - See I. Manthos talk at last DMUK
  - (n,α) and (n,p) reactions, exo- and endothermic
  - Sensitivity to thermal and fast neutrons
- Recent paper, under review 2206.04331

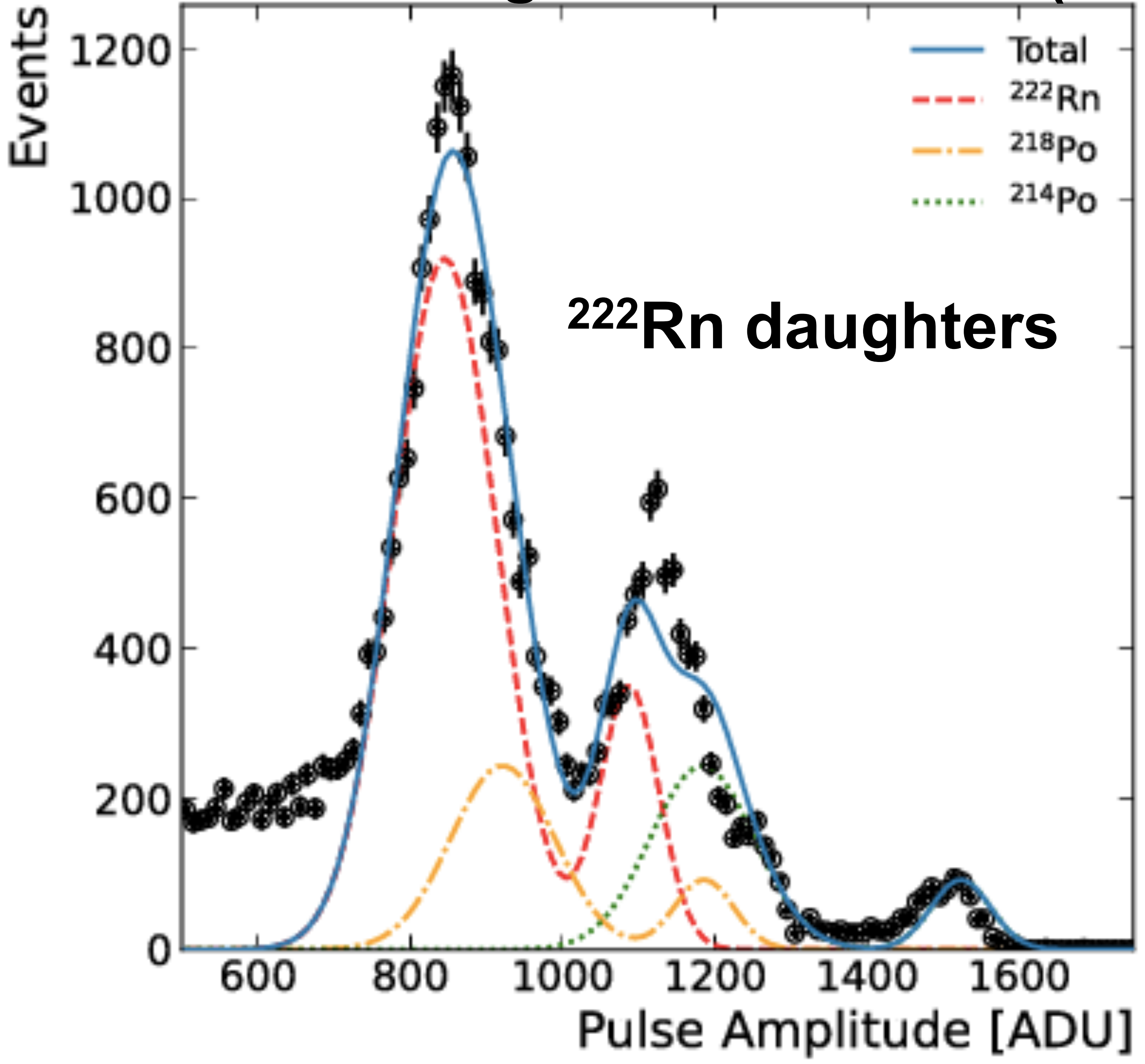


- α and p discrimination would allow fast/thermal discrimination
- Highlighted anode with different gain for this particular ACHINOS
  - Both could be addressed with individual anode read-out
  - Also interesting for BG rejection, and track reconstruction



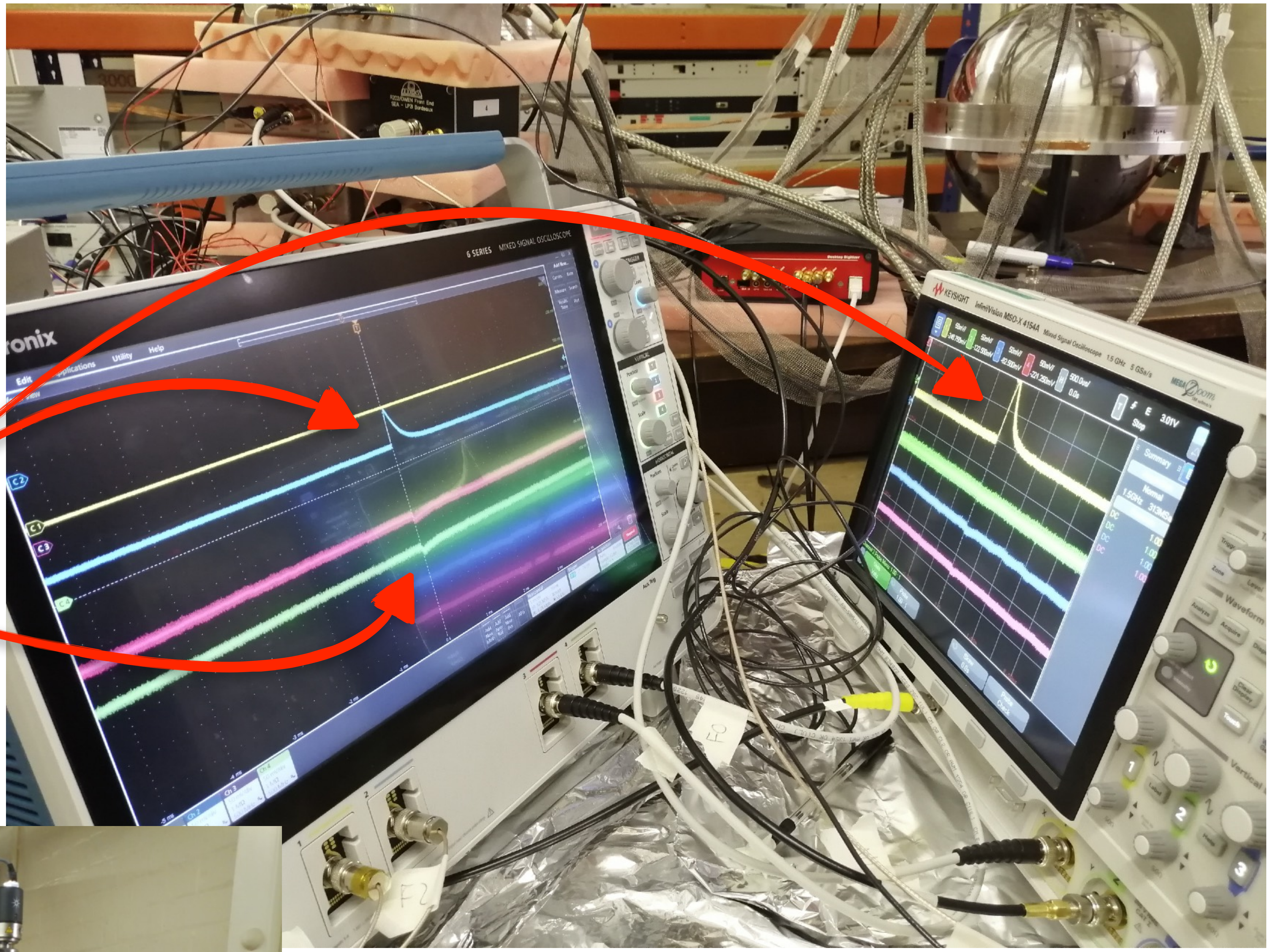
Measurement Improved Processing and Simulation (Lines)

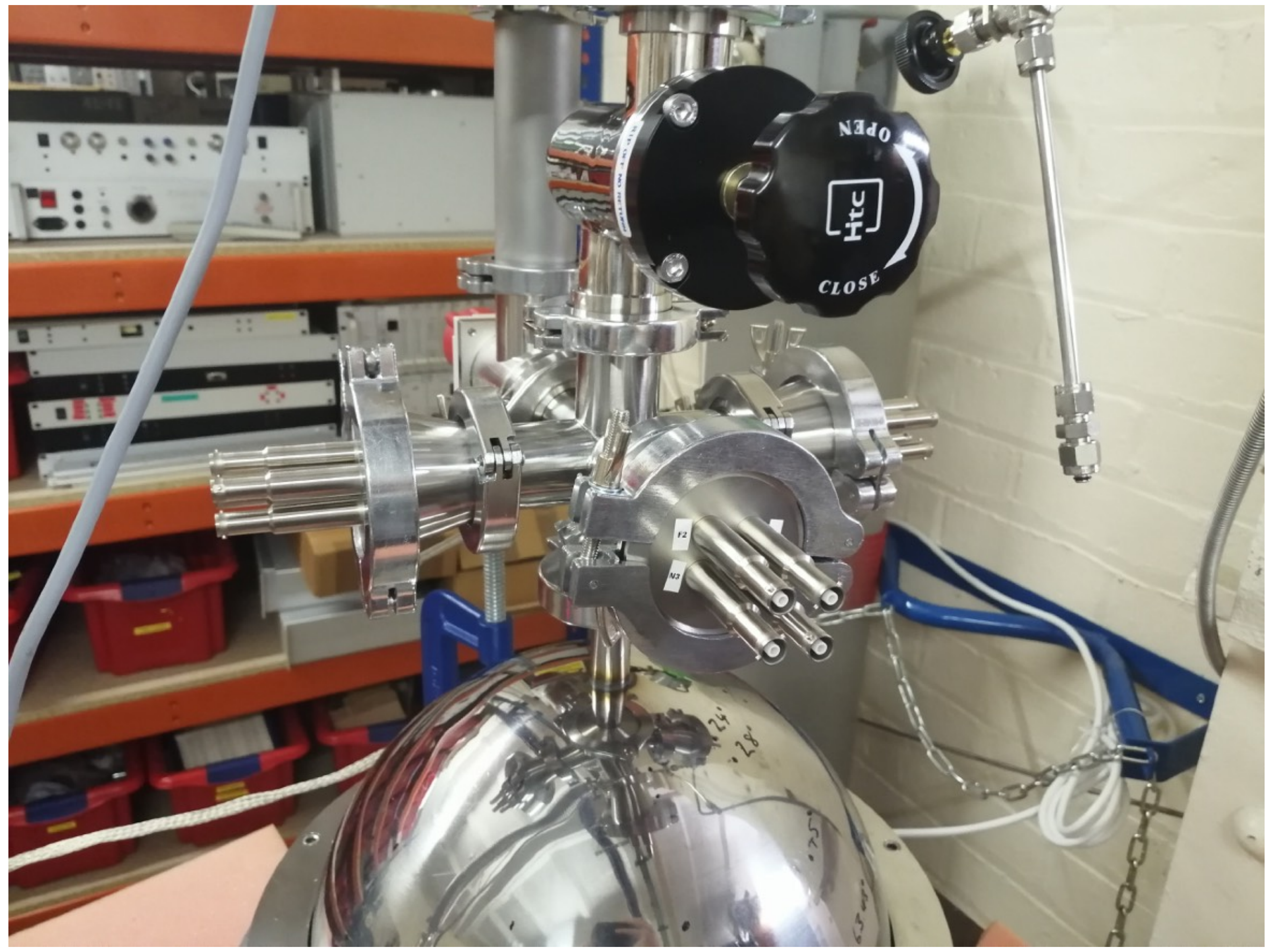


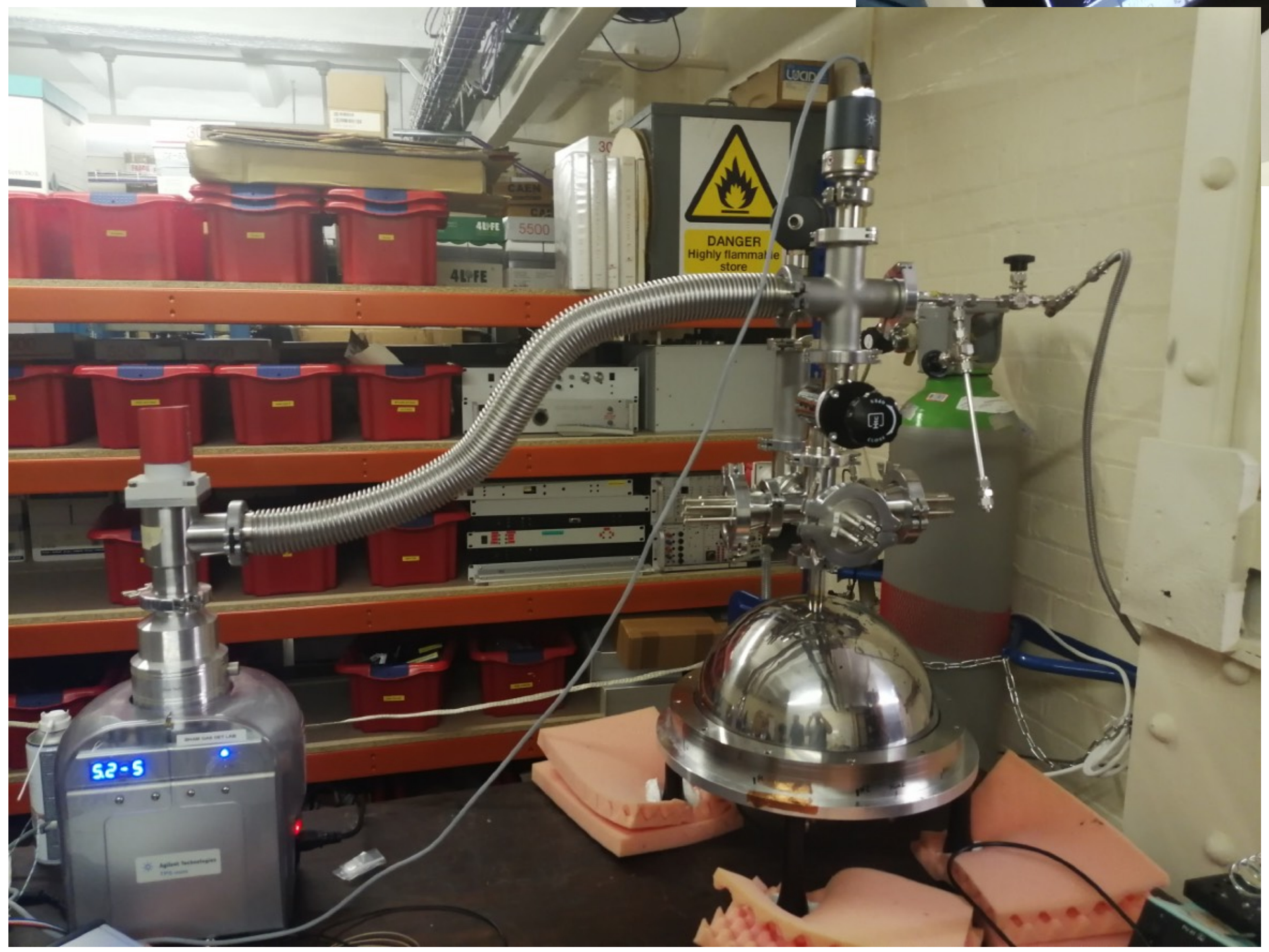


Individual Anode Read-Out

- Work underway to individually read out the 11 anodes
  - Custom-built preamplifier boxes (design, U. Of Bordeaux) built in-house, using CREMAT CR110
- Data with 200 mbar Ar:CH_4 (2%) and ^{210}Po α
  - α ~15 cm range
  - See 'tracks' where multiple anodes collect electrons
  - See induced signal on other anodes (negative)
- Work ongoing, but stay tuned!







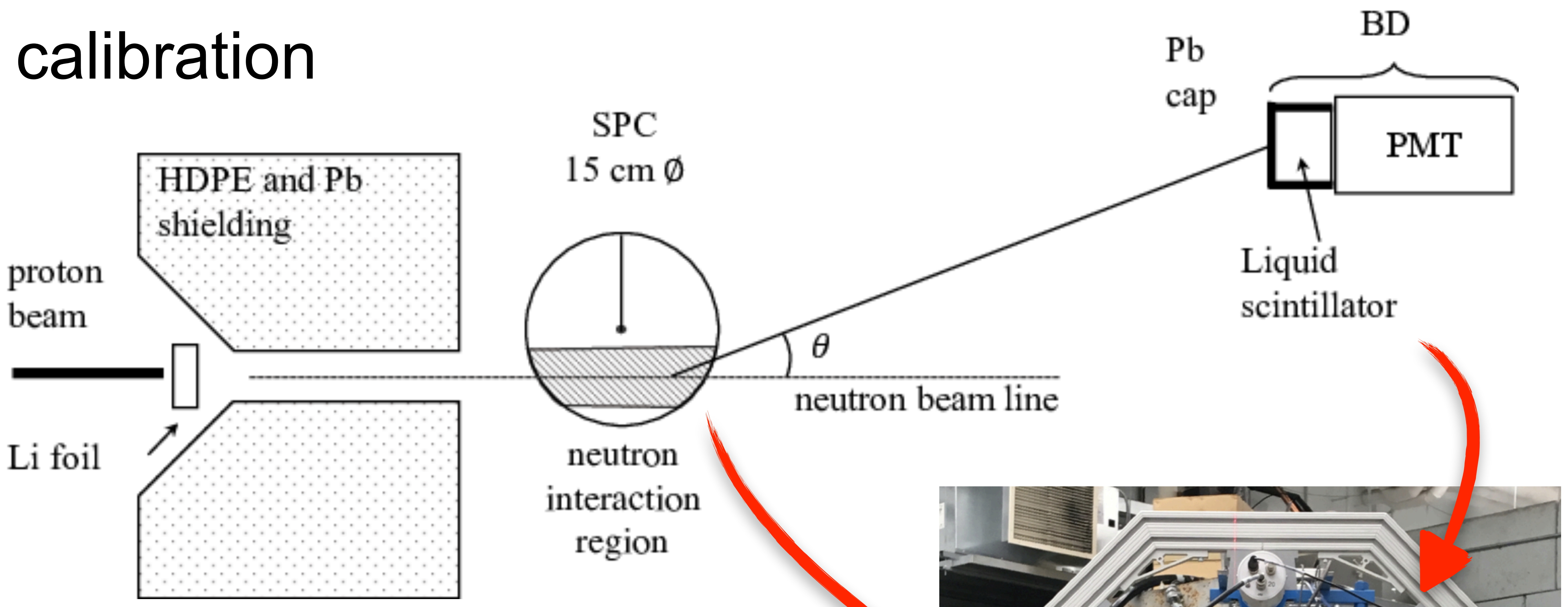
Birmingham
Gaseous
Detectors
Laboratory

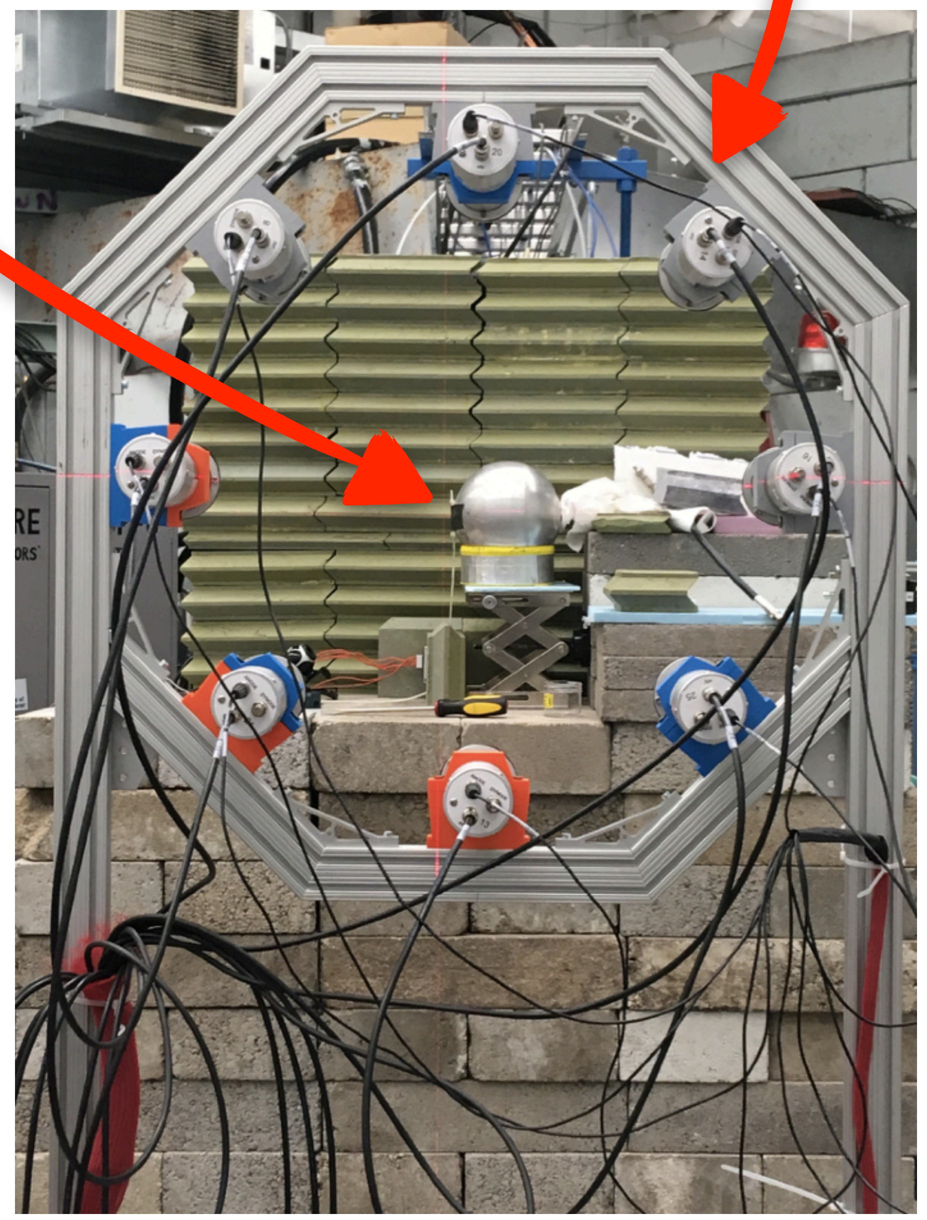
Additional Slides

Quenching Factor Measurements: TUNL

Neutron scattering-induced nuclear recoils in SPC → compare to calibration

- 2 measurement approaches
  - Neutron scattering at TUNL
  - Electron/Ion beam, COMIMAC, at Grenoble



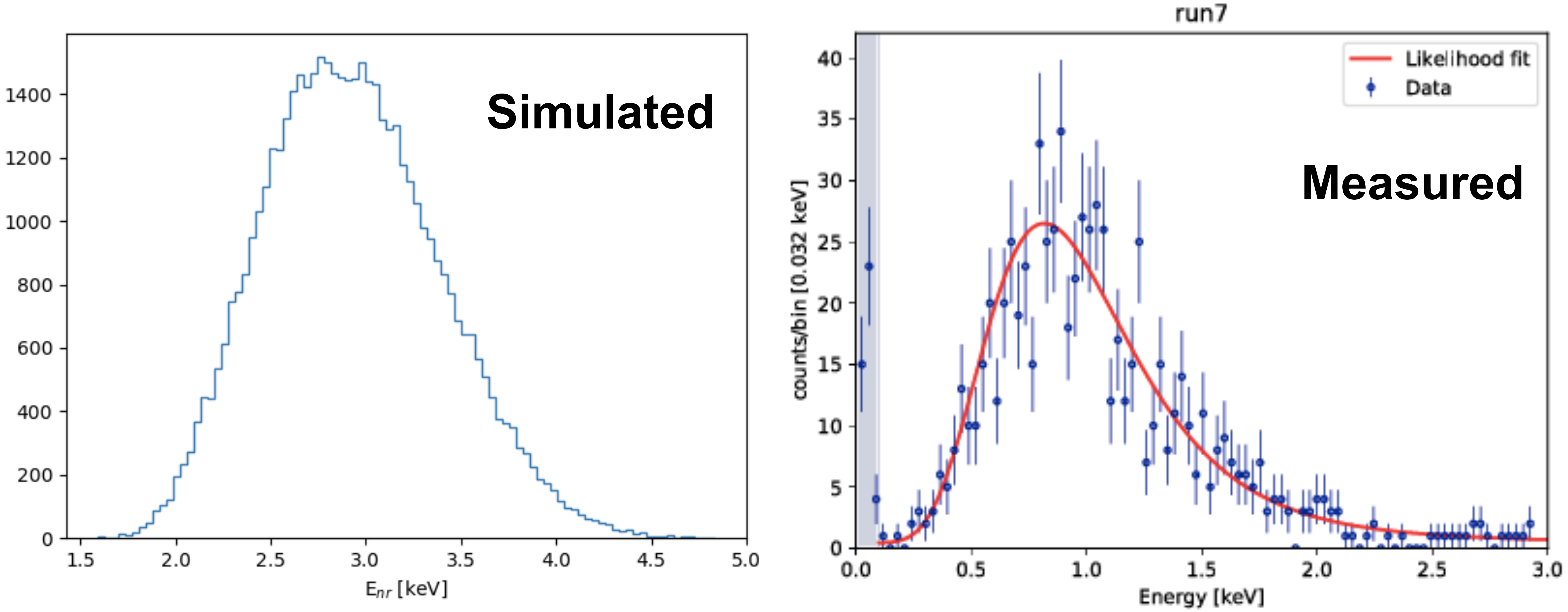


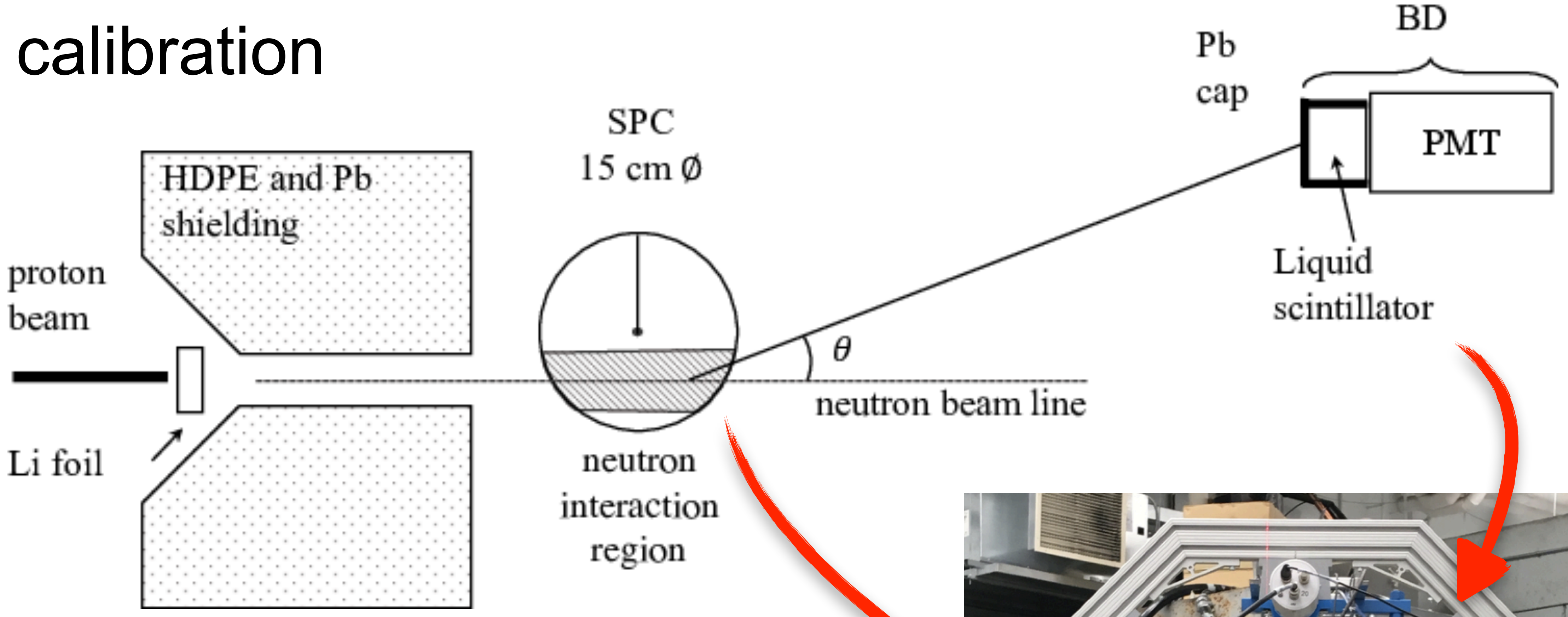
Run	E_{nr} [keV_{nr}]	$\sigma_{E_{nr}}$ [keV_{nr}]	θ [°]	σ_θ [°]
8	6.80	1.15	29.02 ± 0.4	2.45
7	2.93	0.46	18.84 ± 0.1	1.47
14	2.02	0.29	15.63 ± 0.3	1.12
9	1.70	0.26	14.33 ± 0.06	1.1
10	1.30	0.2	12.48 ± 0.05	0.94
14	1.03	0.2	11.13 ± 0.3	1.1
11	0.74	0.11	9.4 ± 0.03	0.69
14	0.34	0.11	6.33 ± 0.26	1.1

Quenching Factor Measurements: TUNL

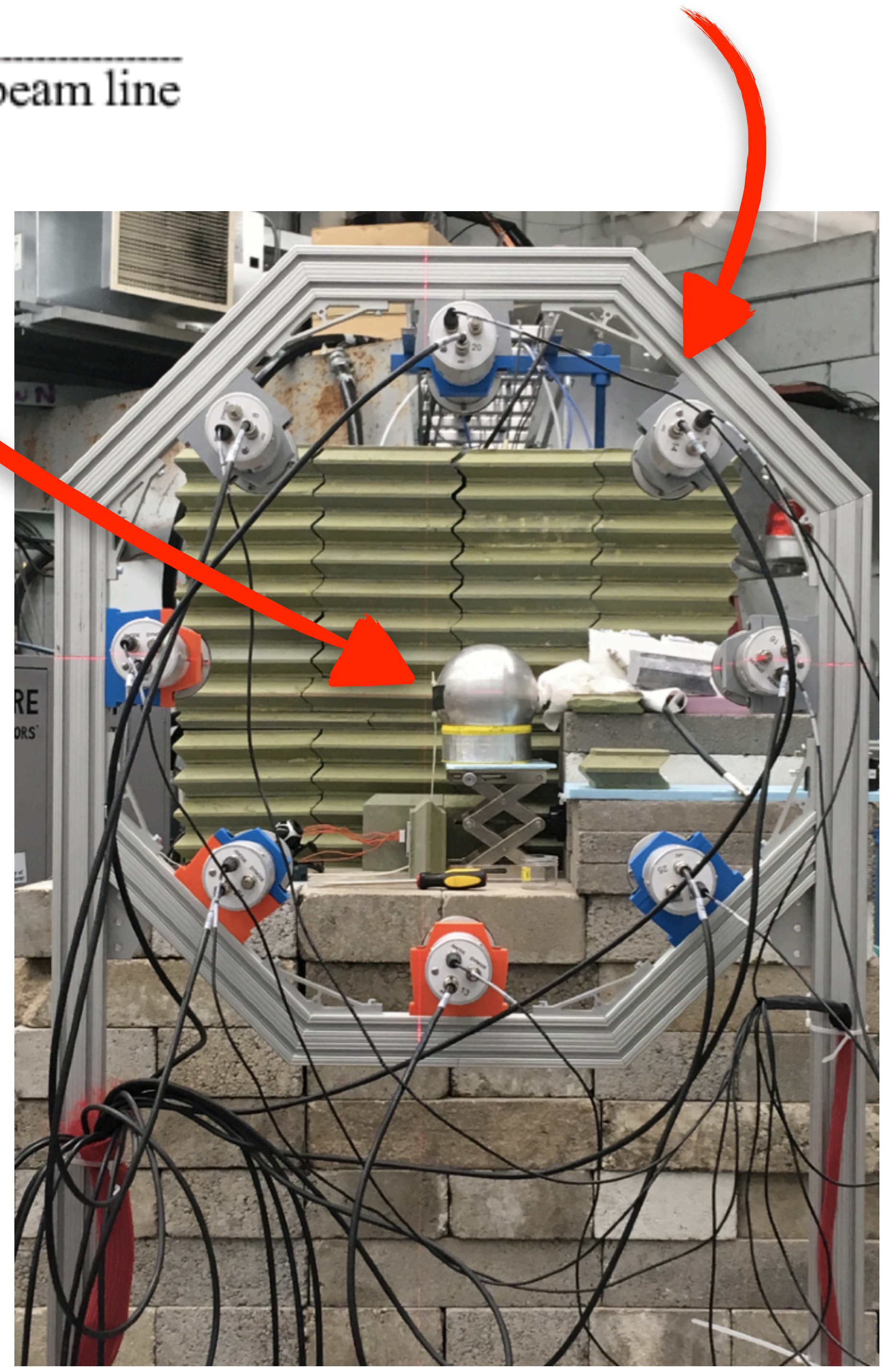
Neutron scattering-induced nuclear recoils in SPC → compare to calibration

Recoil Spectrum





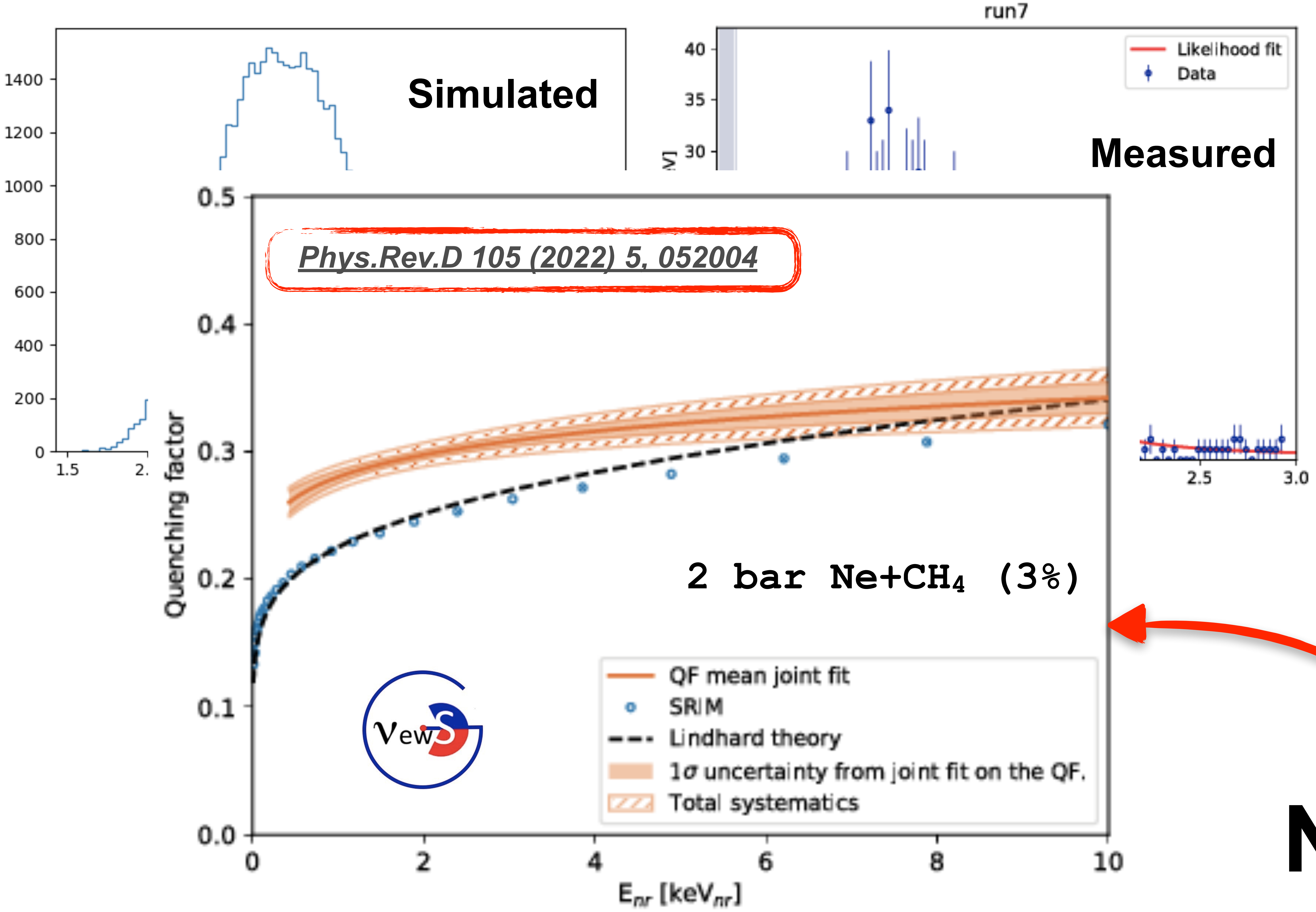
Run	E_{nr} [keV_{nr}]	$\sigma_{E_{nr}}$ [keV_{nr}]	θ [°]	σ_θ [°]
8	6.80	1.15	29.02 ± 0.4	2.45
7	2.93	0.46	18.84 ± 0.1	1.47
14	2.02	0.29	15.63 ± 0.3	1.12
9	1.70	0.26	14.33 ± 0.06	1.1
10	1.30	0.2	12.48 ± 0.05	0.94
14	1.03	0.2	11.13 ± 0.3	1.1
11	0.74	0.11	9.4 ± 0.03	0.69
14	0.34	0.11	6.33 ± 0.26	1.1

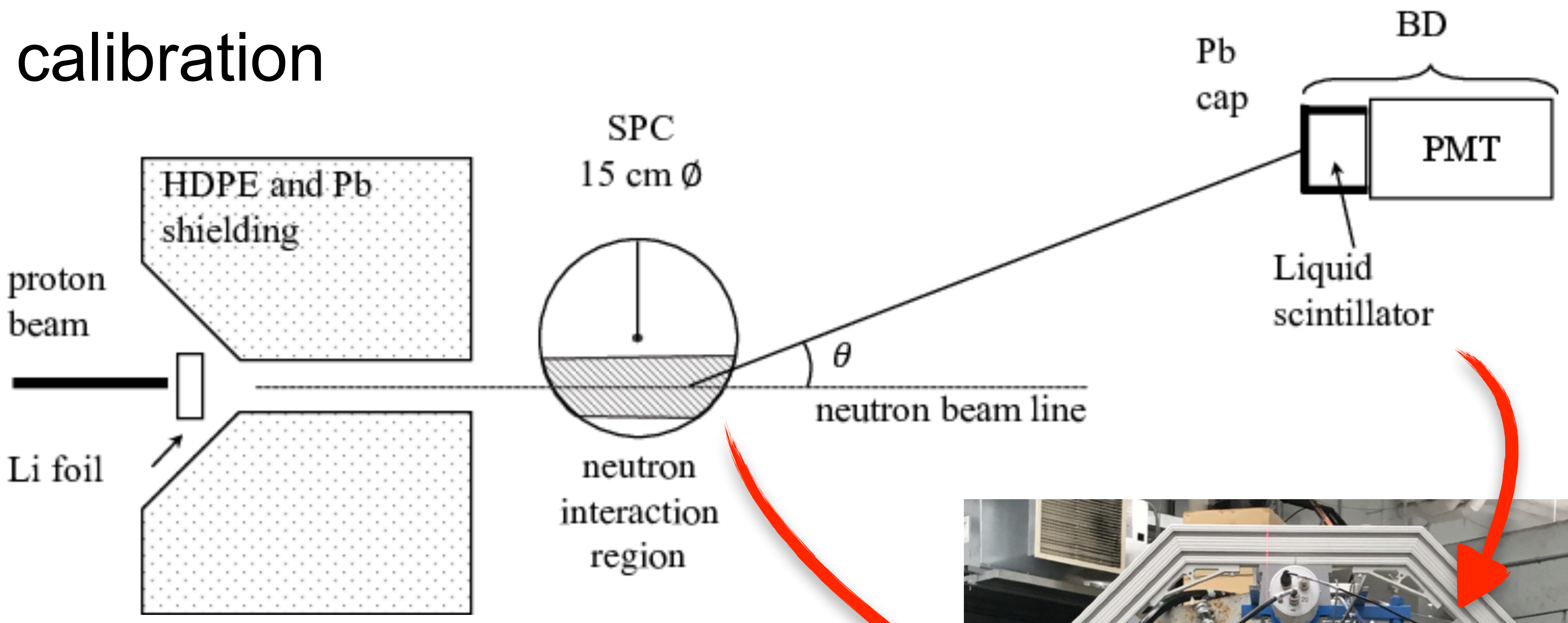


Quenching Factor Measurements: TUNL

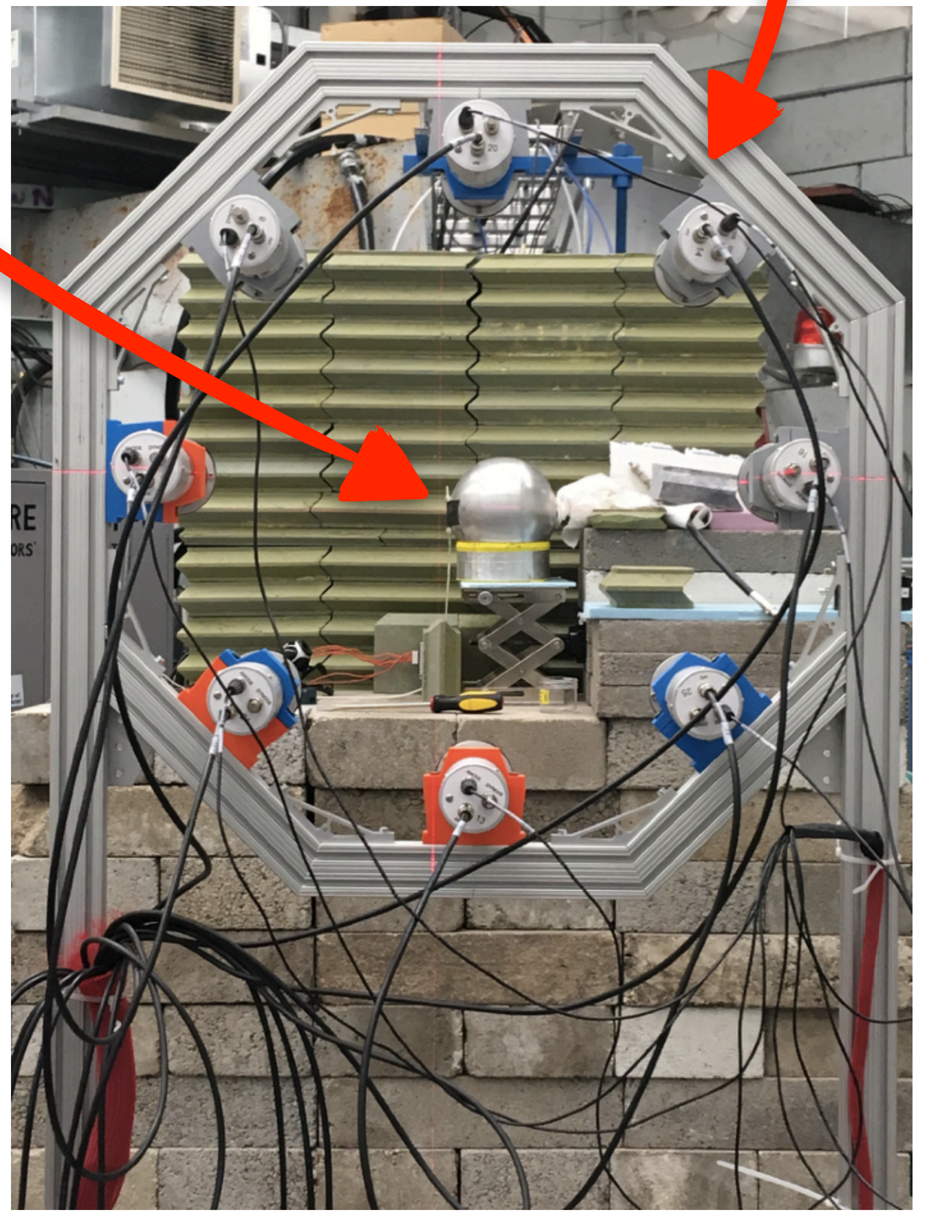
Neutron scattering-induced nuclear recoils in SPC → compare to calibration

Recoil Spectrum



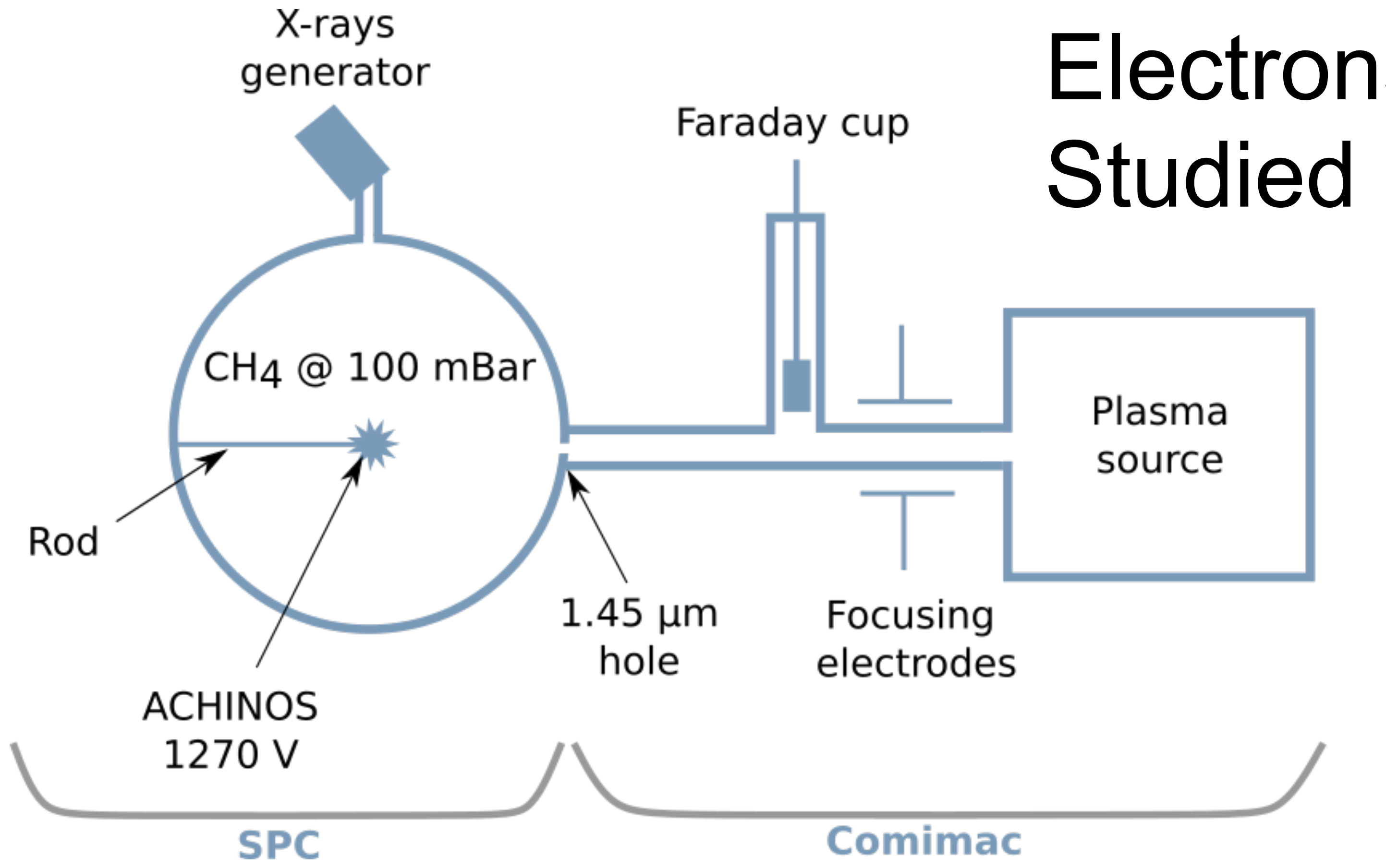


Run	E_{nr} [keV_{nr}]	$\sigma_{E_{nr}}$ [keV_{nr}]	θ [°]	σ_θ [°]
8	6.80	1.15	29.02 ± 0.4	2.45
7	2.93	0.46	18.84 ± 0.1	1.47
14	2.02	0.29	15.63 ± 0.3	1.12
9	1.70	0.26	14.33 ± 0.06	1.1
10	1.30	0.2	12.48 ± 0.05	0.94
14	1.03	0.2	11.13 ± 0.3	1.1
11	0.74	0.11	9.4 ± 0.03	0.69
14	0.34	0.11	6.33 ± 0.26	1.1



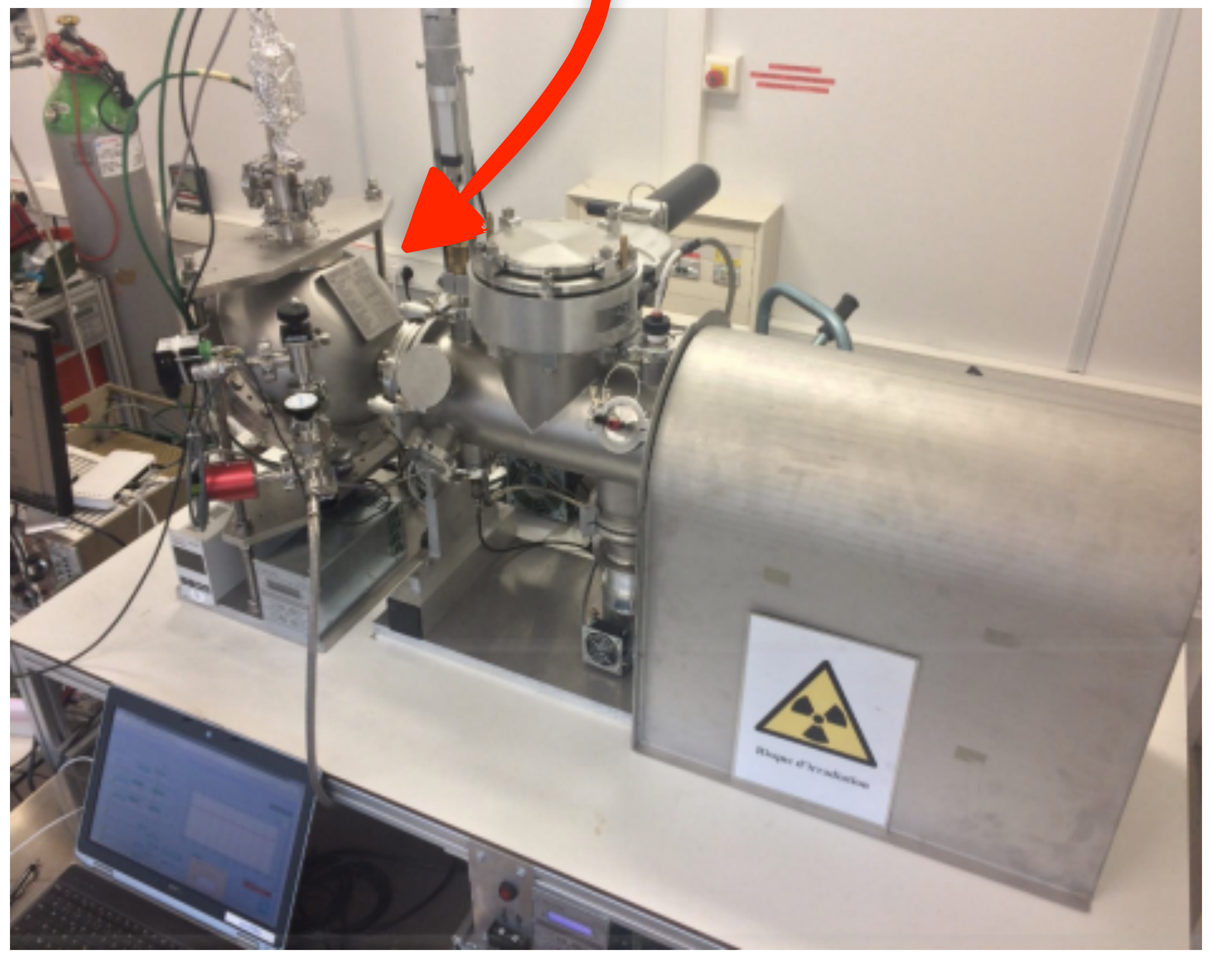
New Result 2022!

Quenching Factor Measurements:

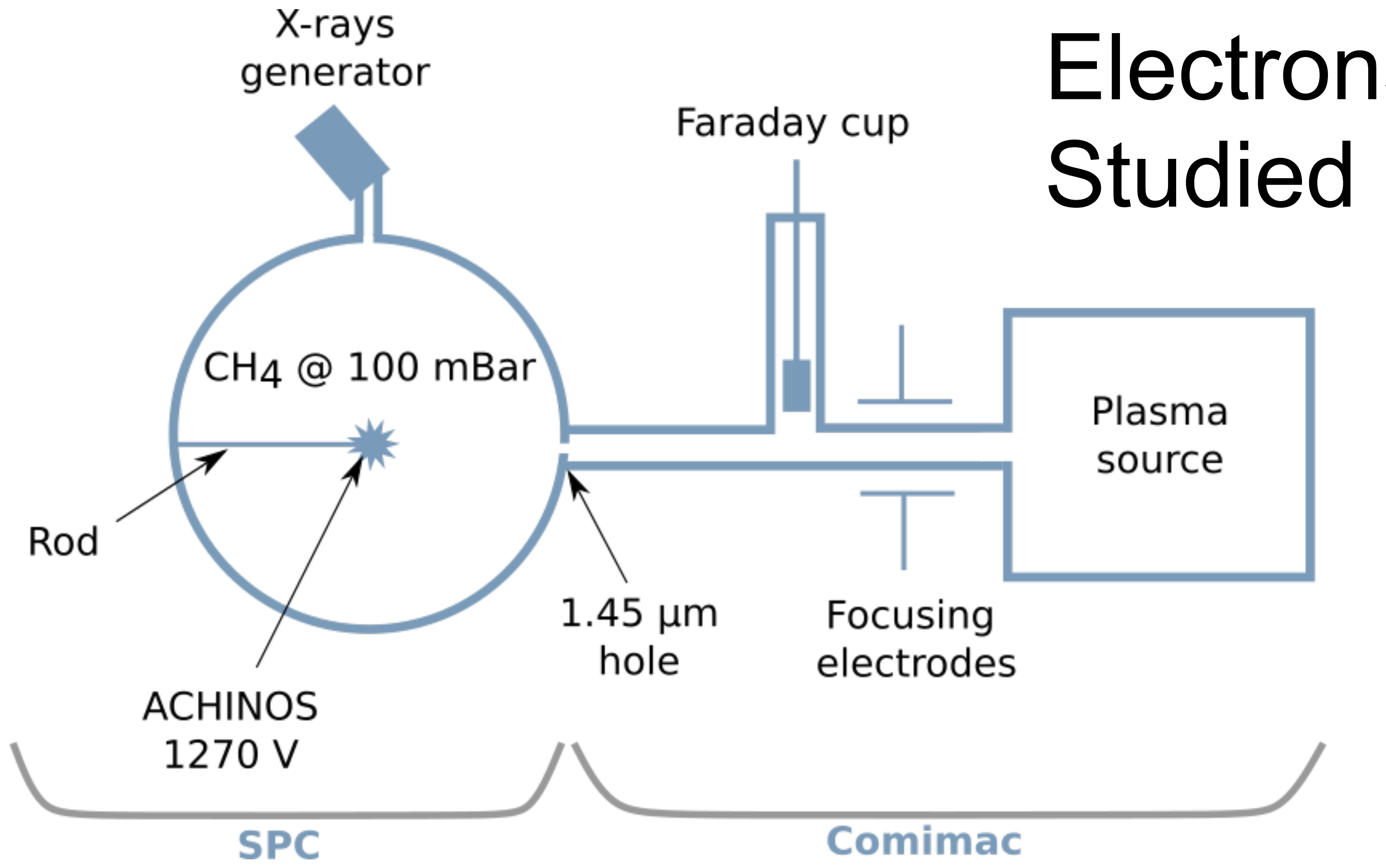


Electrons and ions directed into SPC → compare response
Studied ions 2 - 13 keV, calibrated with e^- 1.5 - 13 keV

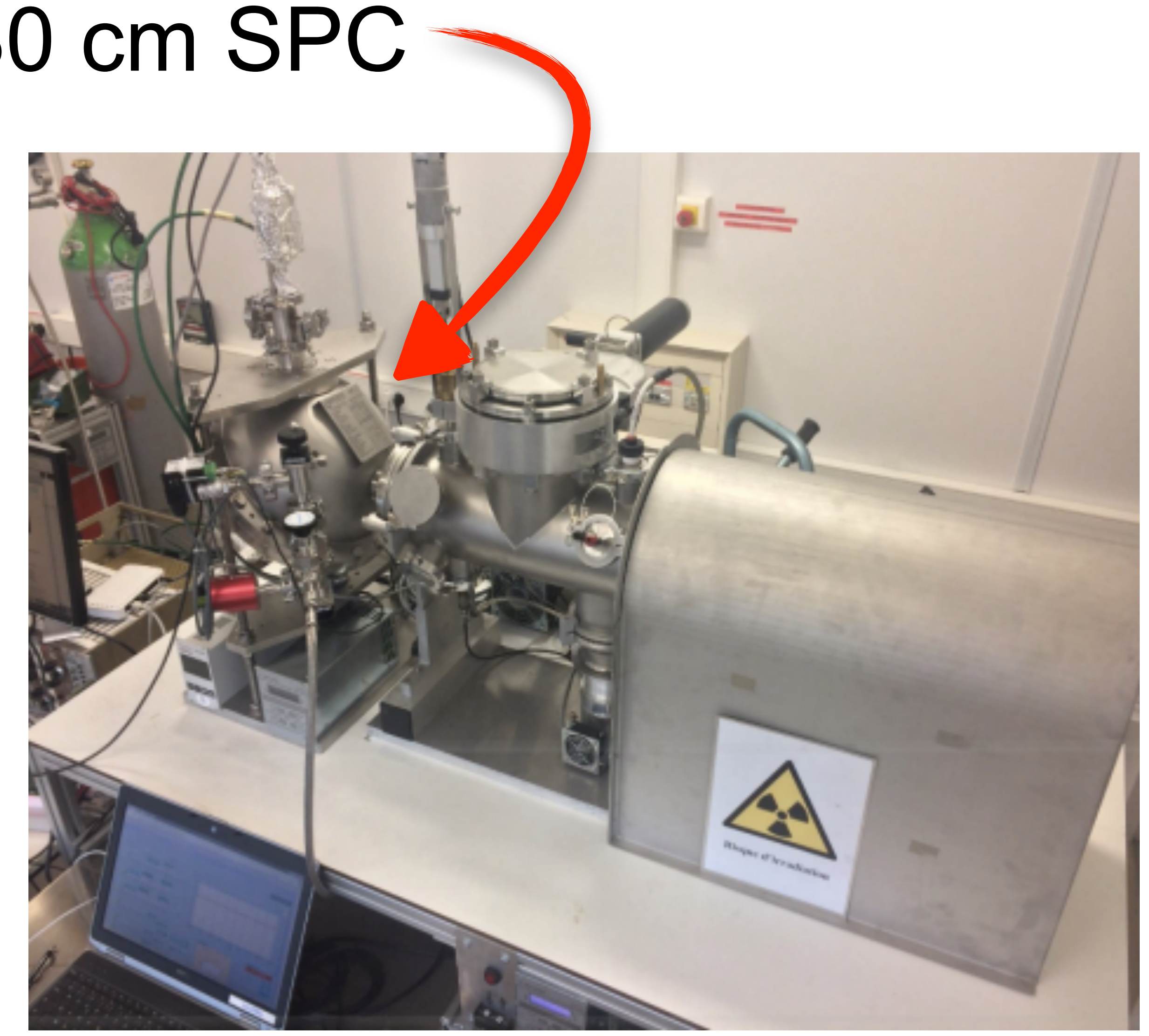
⌀30 cm SPC



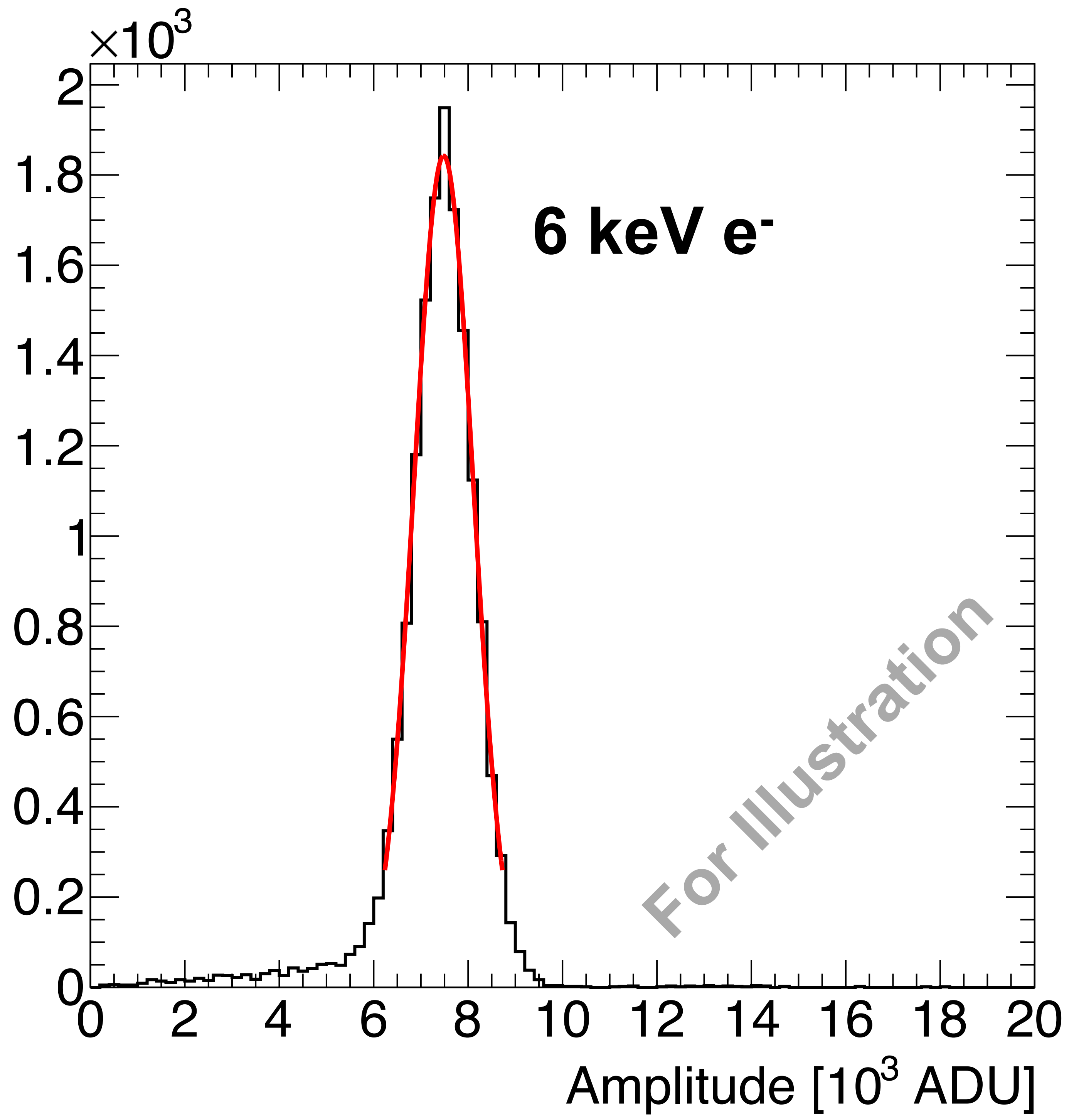
Quenching Factor Measurements:

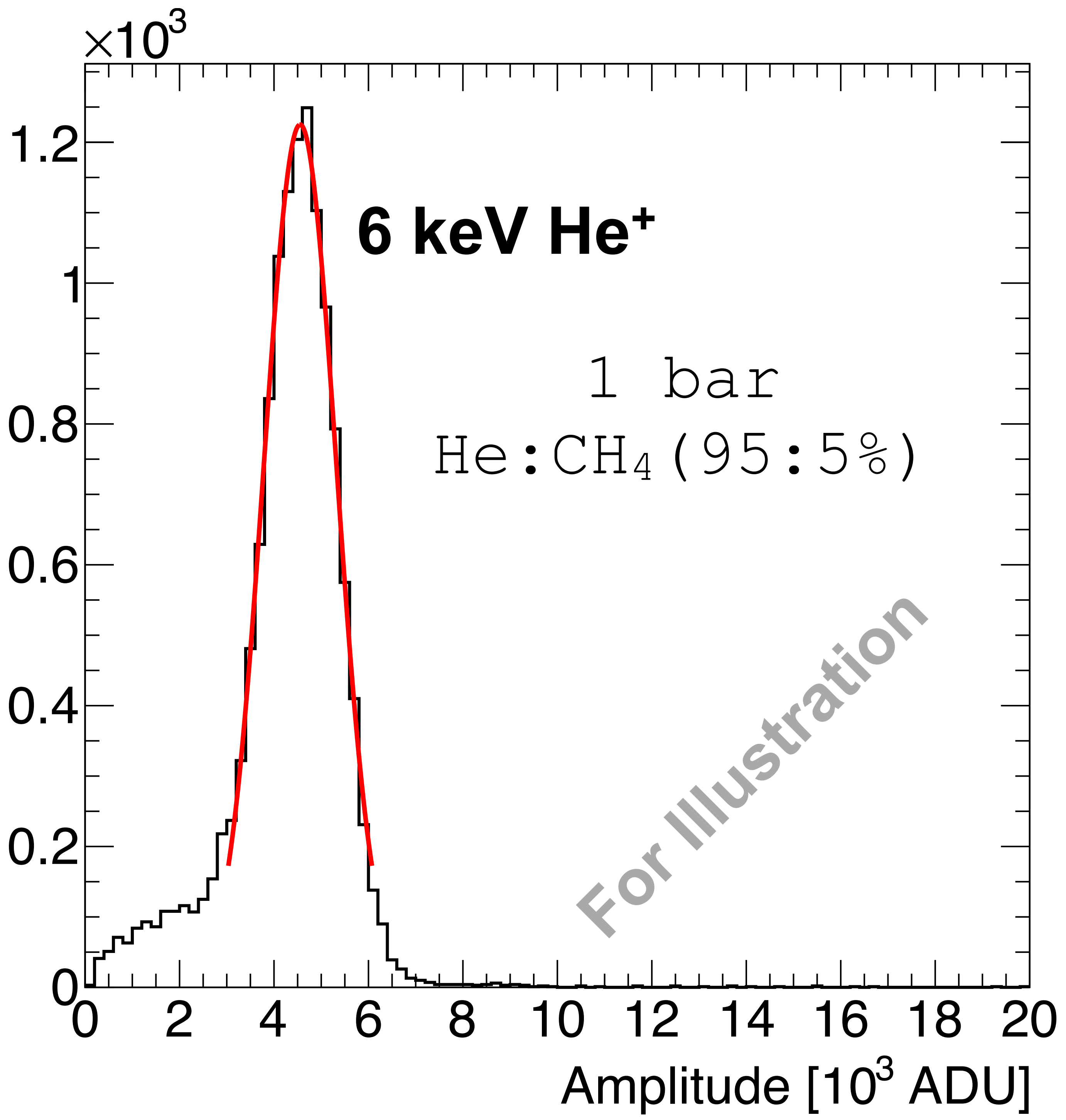


⌀30 cm SPC



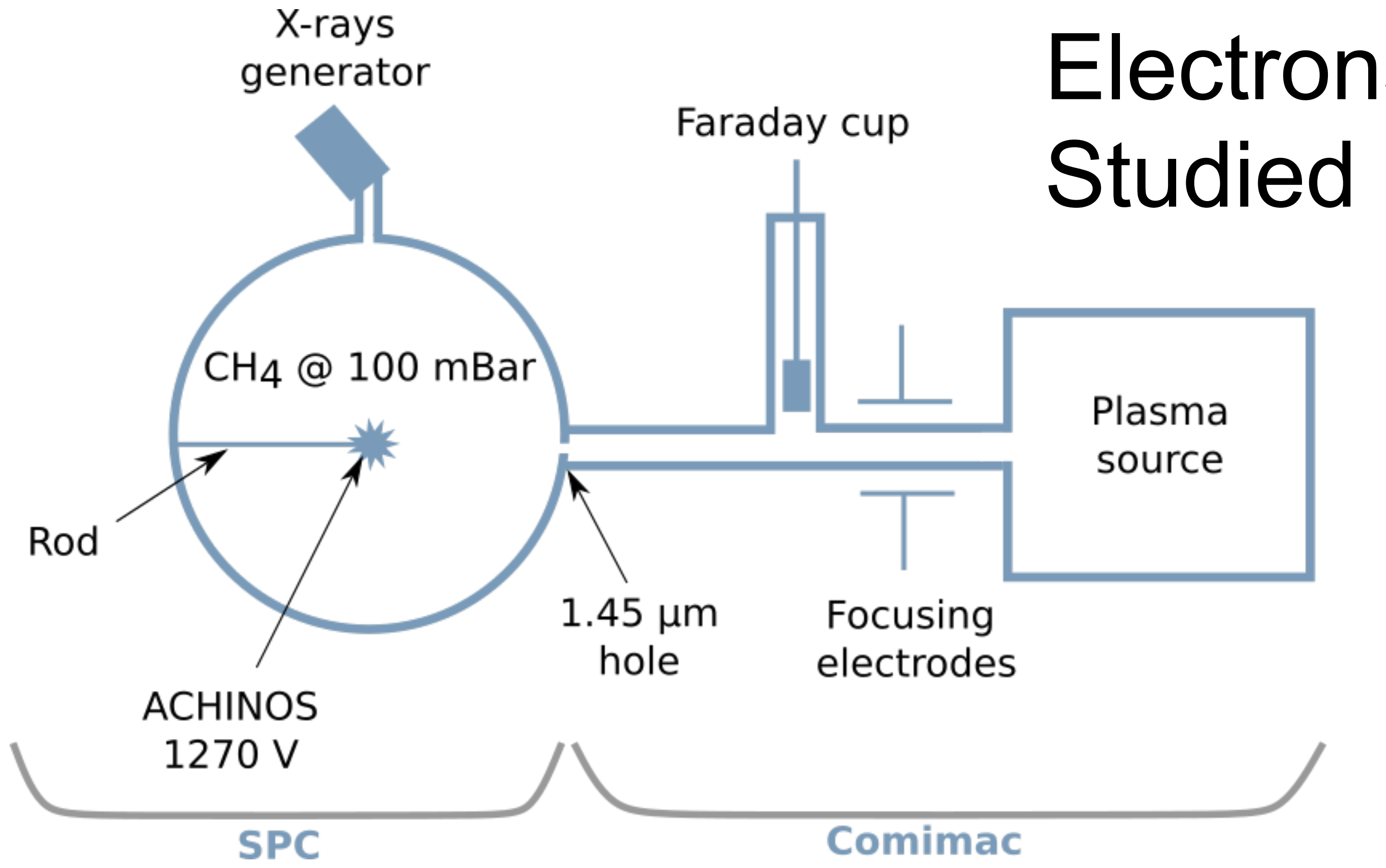
Electrons and ions directed into SPC → compare response
Studied ions 2 - 13 keV, calibrated with e⁻ 1.5 - 13 keV



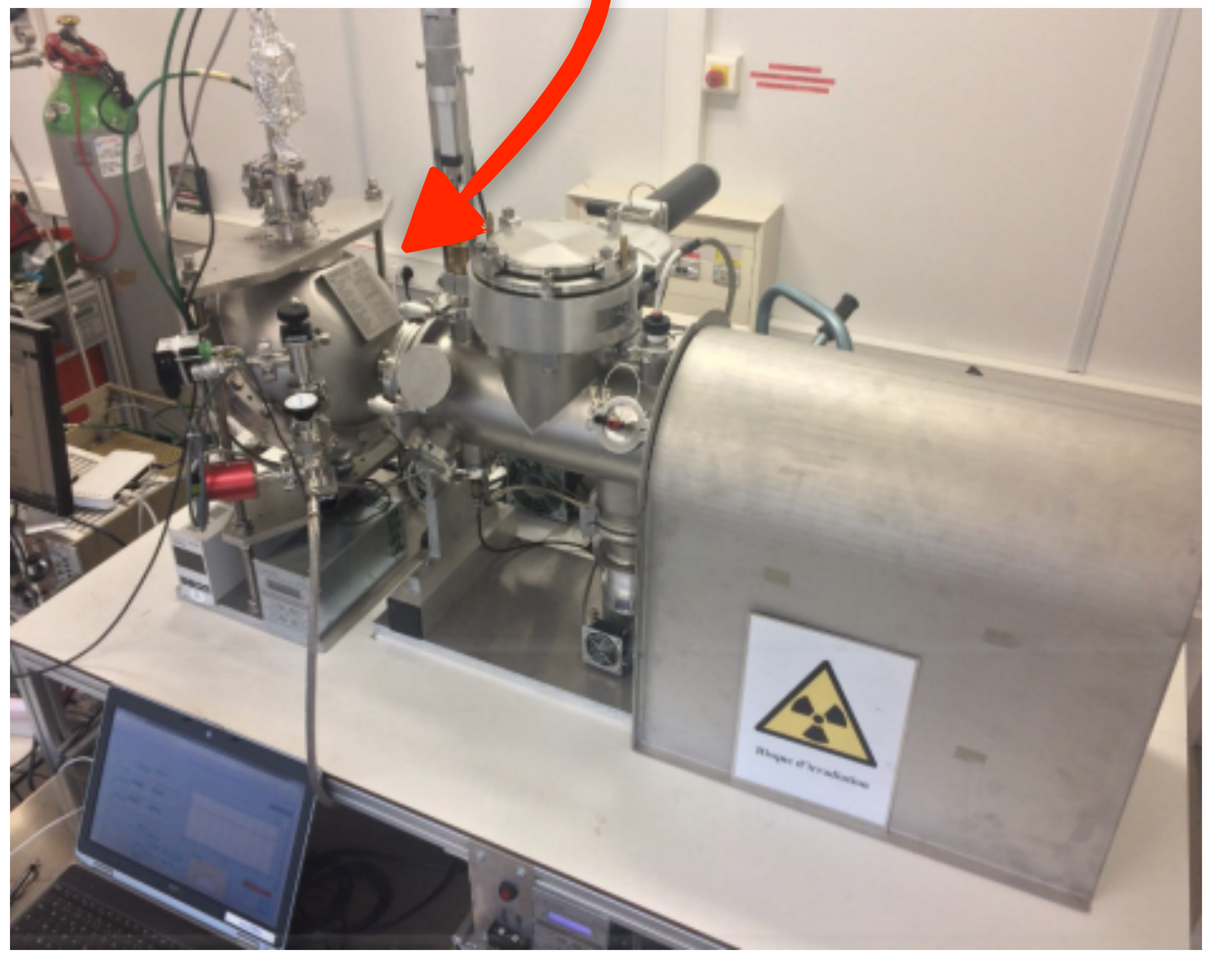


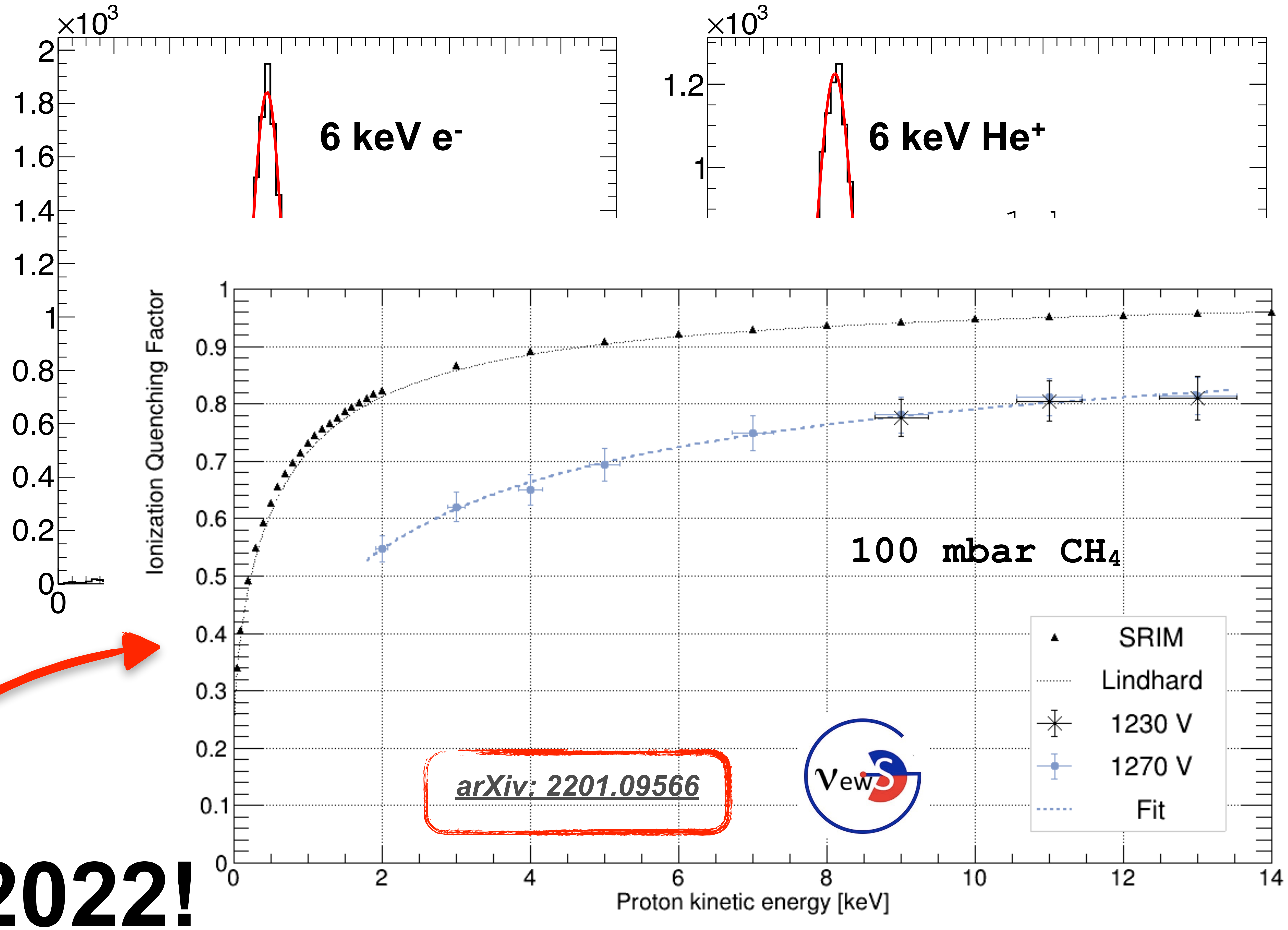
Quenching Factor Measurements:

Electrons and ions directed into SPC → compare response
Studied ions 2 - 13 keV, calibrated with e^- 1.5 - 13 keV



⌀30 cm SPC



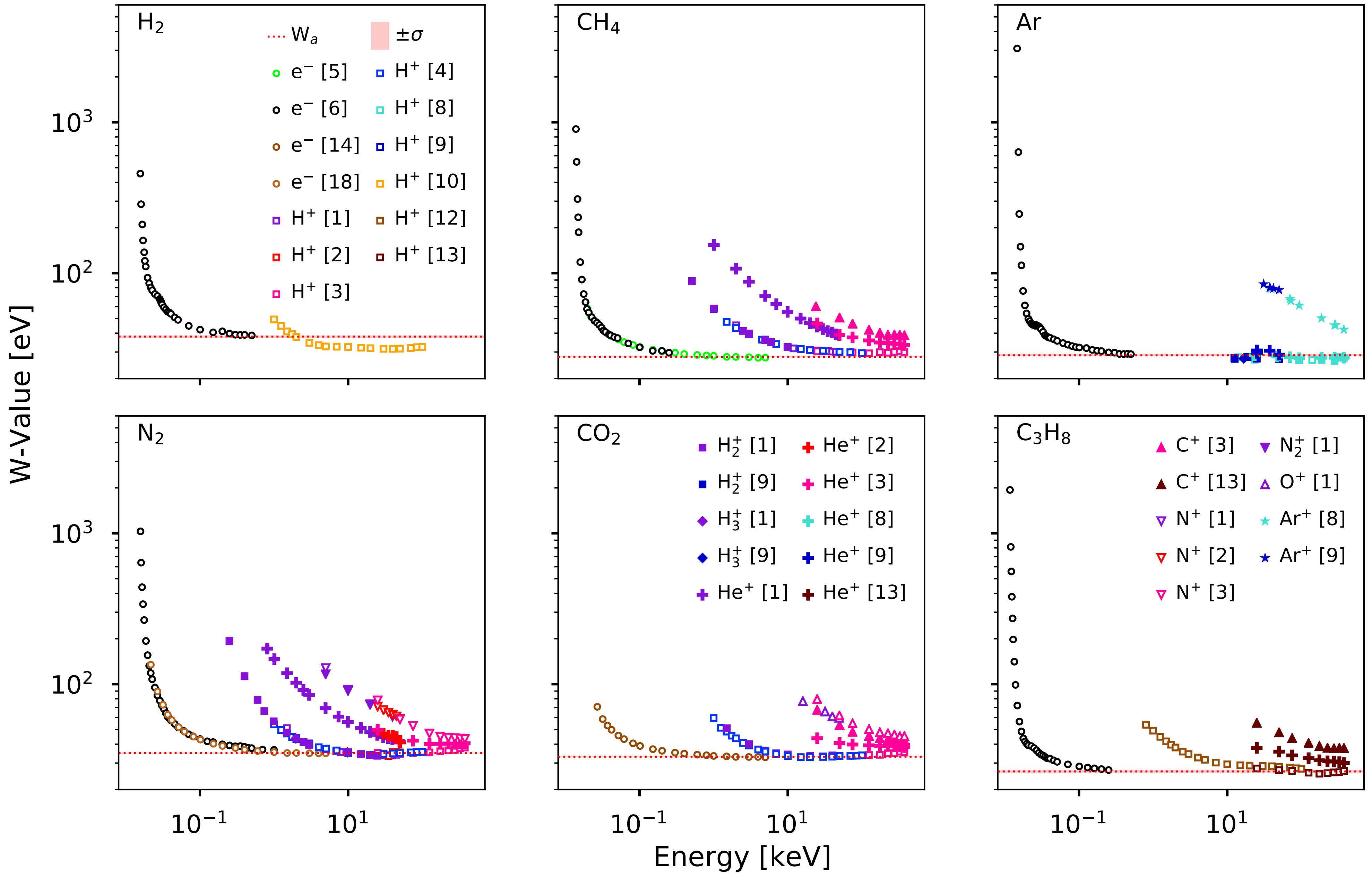


New Result 2022!

Quenching Factor Estimates: W-Values

- W-value: **Average energy** required to produce **electron-ion pair**
- W different for electrons and ions, and varies with energy
  - Difference is quantified by QF
- W of electrons and ions in gases prev. studied for dosimetry
  - Comparing asymptotic electron W-value and W(E) for ions, get QF

Astropart.Phys. 141 (2022) 102707

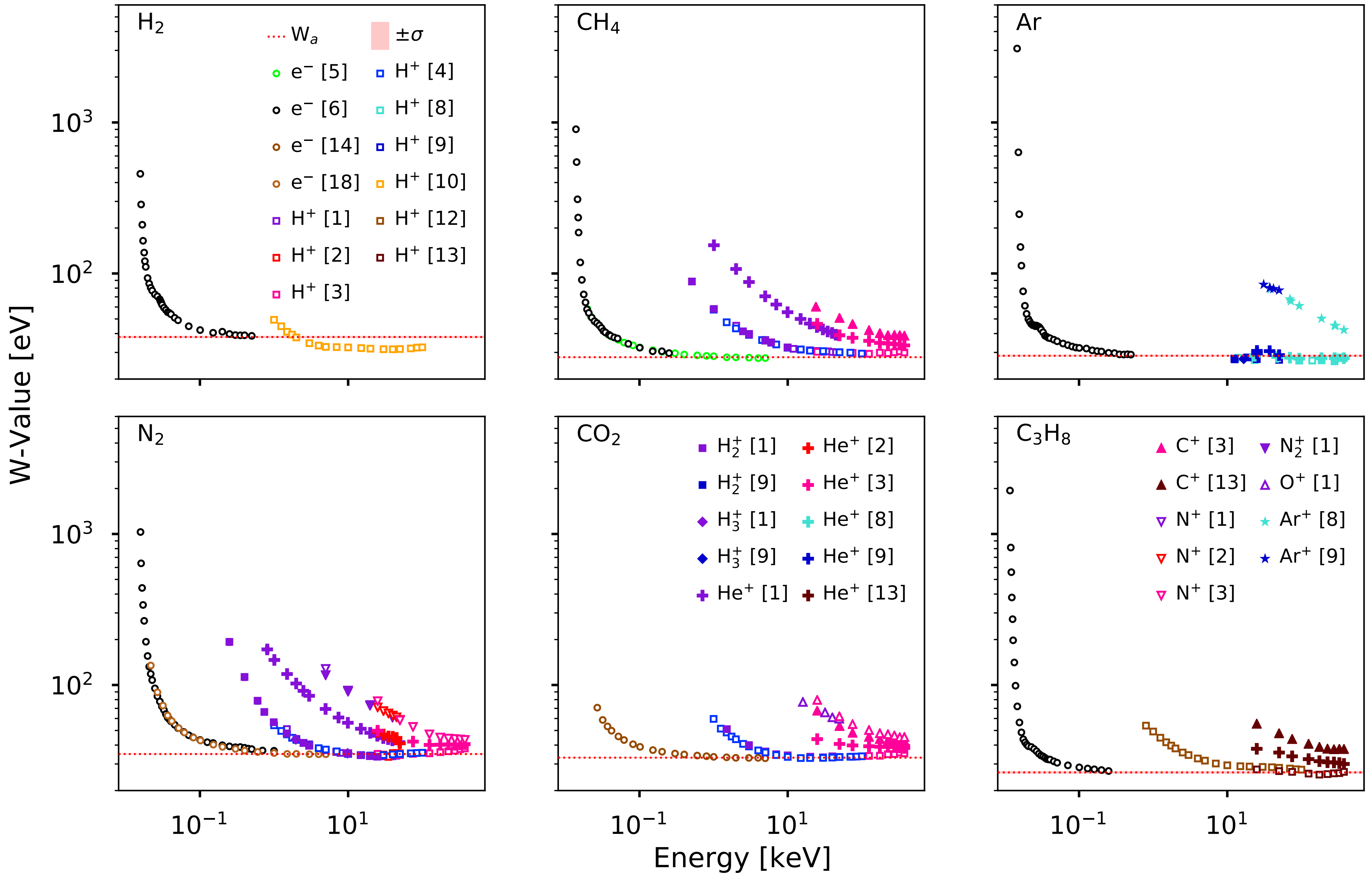


Quenching Factor Estimates: W-Values

- W-value: **Average energy** required to produce **electron-ion pair**
- W different for electrons and ions, and varies with energy
  - Difference is quantified by QF
- W of electrons and ions in gases prev. studied for dosimetry
  - Comparing asymptotic electron W-value and W(E) for ions, get QF

Gas	W [eV]	
	ICRU	Asymptotic
H_2	36.5±0.7	38.0±0.8
CH_4	27.3±0.6	27.90± 0.01
N_2	34.8±0.7	34.91±0.17
Ar	26.4±0.5	28.5±0.6
CO_2	33.0±0.7	33.02±0.12
C_3H_8	24.0±0.5	26.4±0.5

Astropart.Phys. 141 (2022) 102707

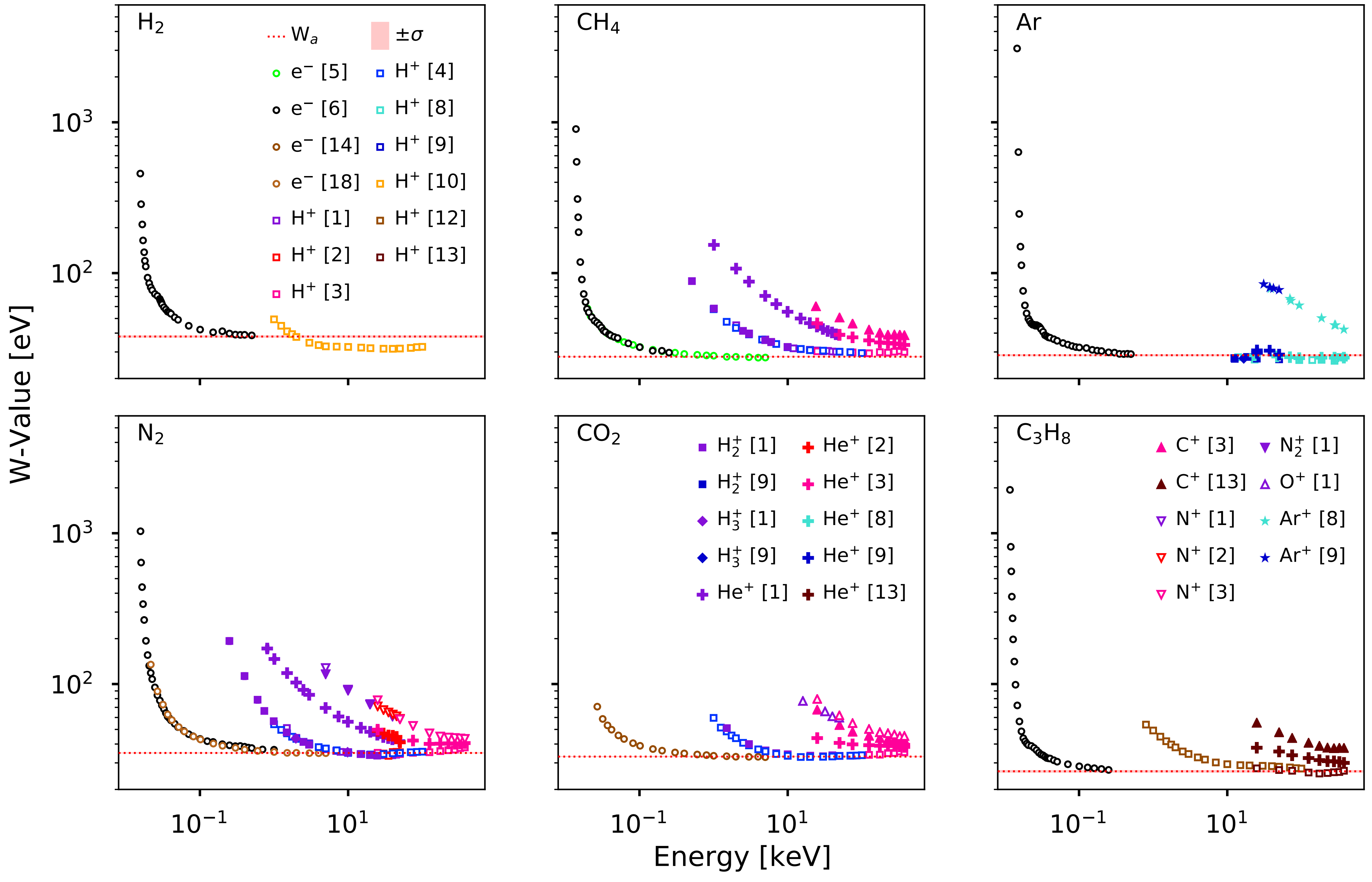


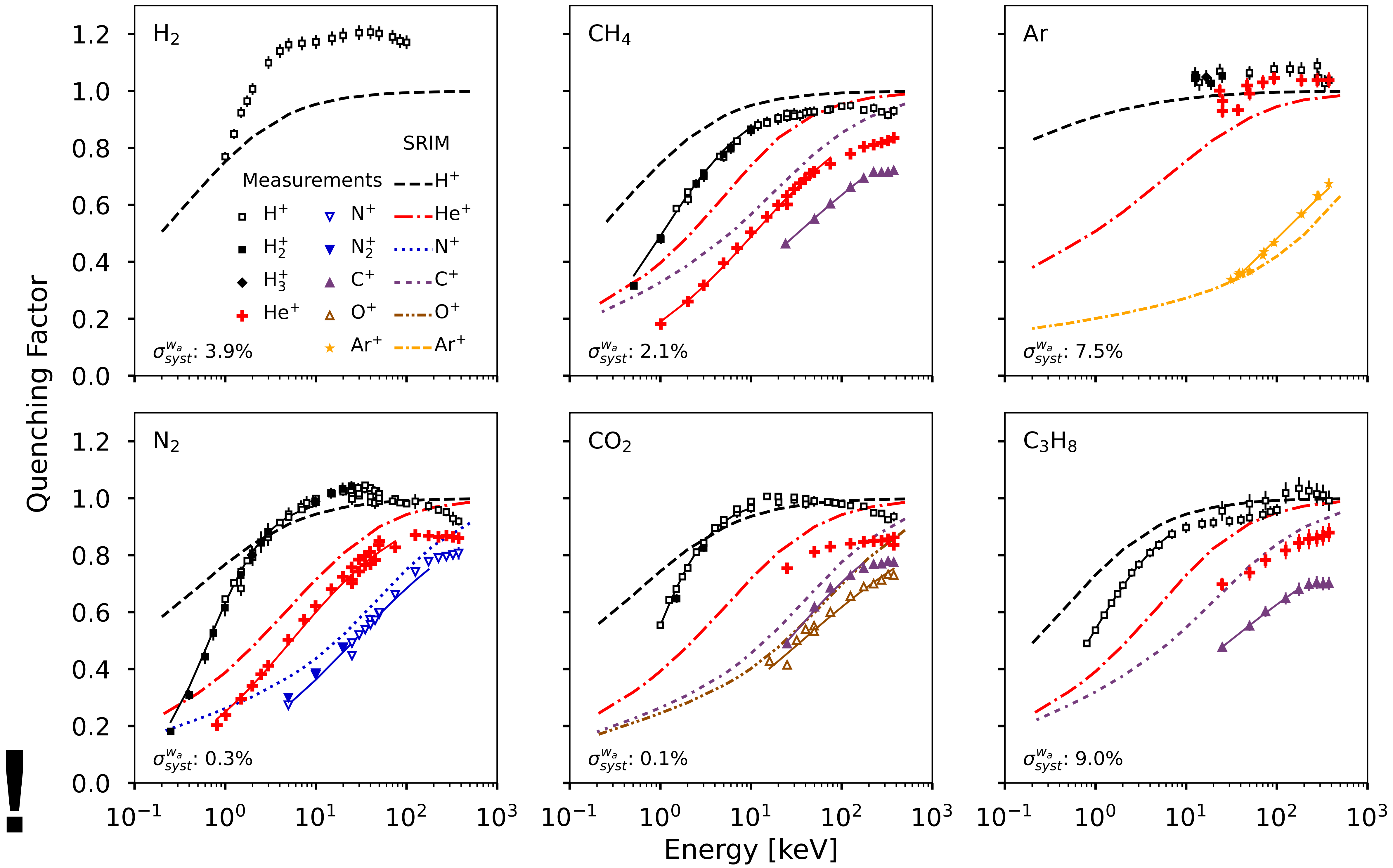
Quenching Factor Estimates: W-Values

- W-value: **Average energy** required to produce **electron-ion pair**
- W different for electrons and ions, and varies with energy
  - Difference is quantified by QF
- W of electrons and ions in gases prev. studied for dosimetry
  - Comparing asymptotic electron W-value and W(E) for ions, get QF

Gas	W [eV] ICRU	W [eV] Asymptotic
H_2	36.5±0.7	38.0±0.8
CH_4	27.3±0.6	27.90± 0.01
N_2	34.8±0.7	34.91±0.17
Ar	26.4±0.5	28.5±0.6
CO_2	33.0±0.7	33.02±0.12
C_3H_8	24.0±0.5	26.4±0.5

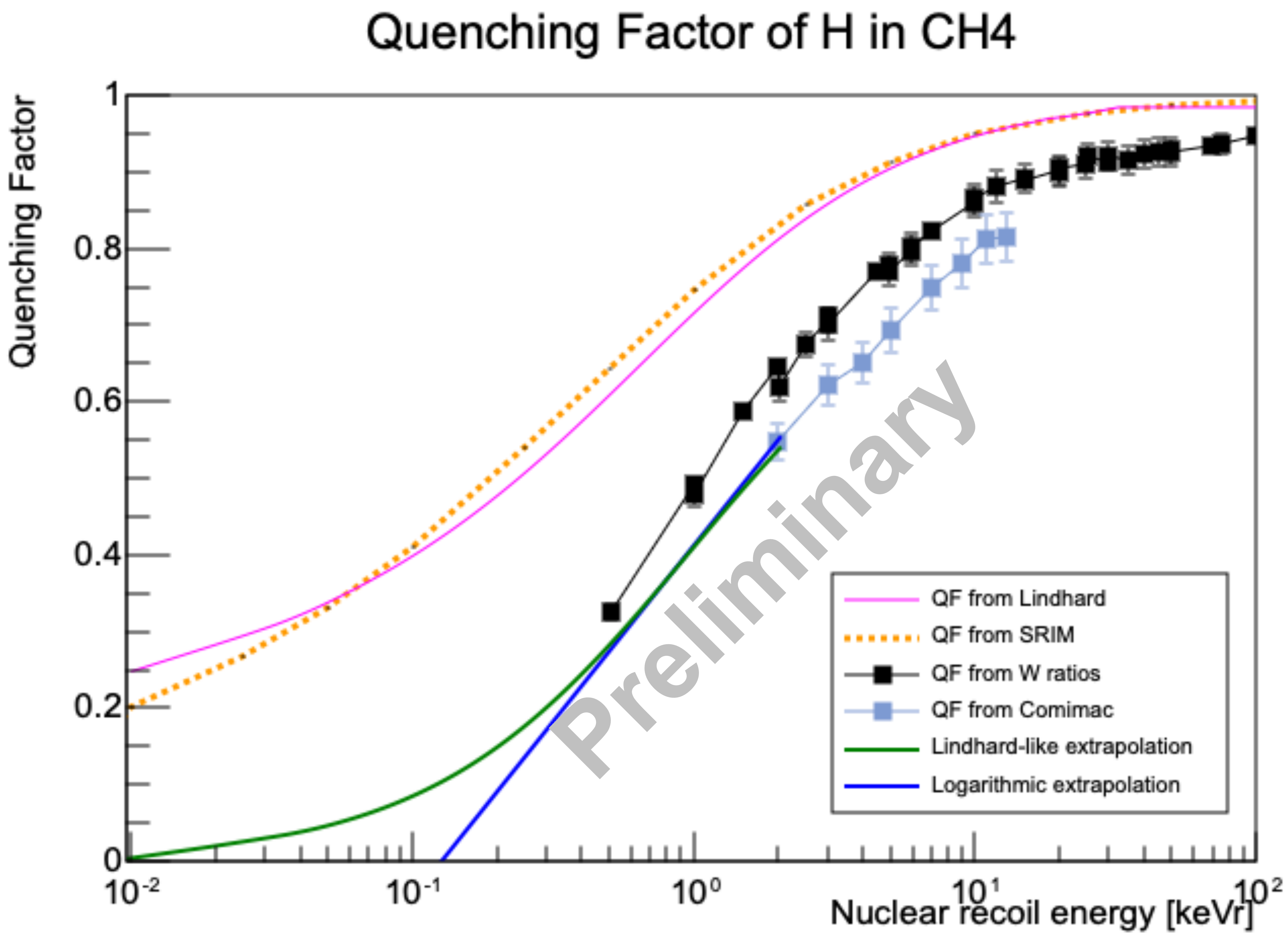
Astropart.Phys. 141 (2022) 102707





New Result 2022!

Quenching Factor

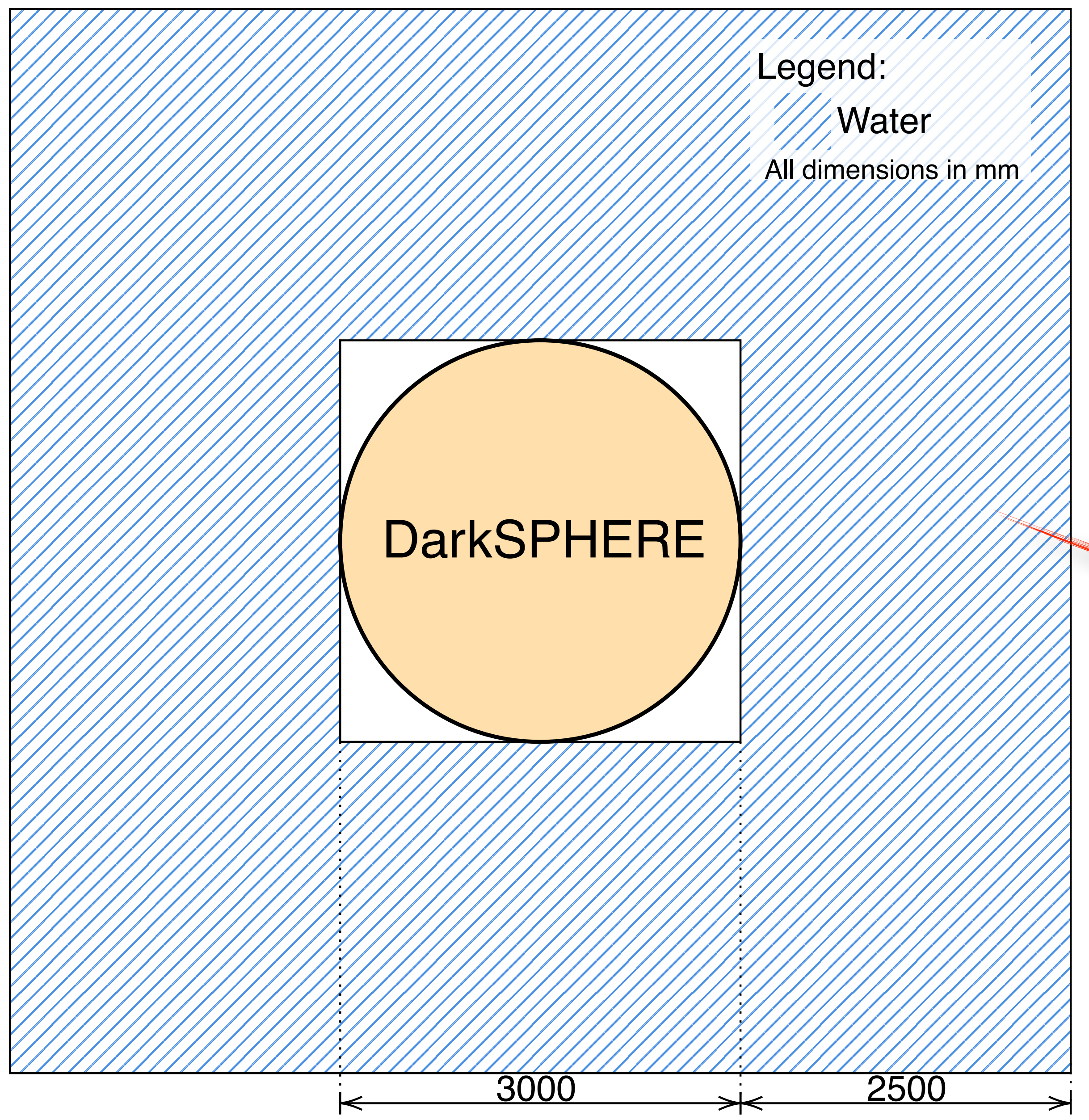


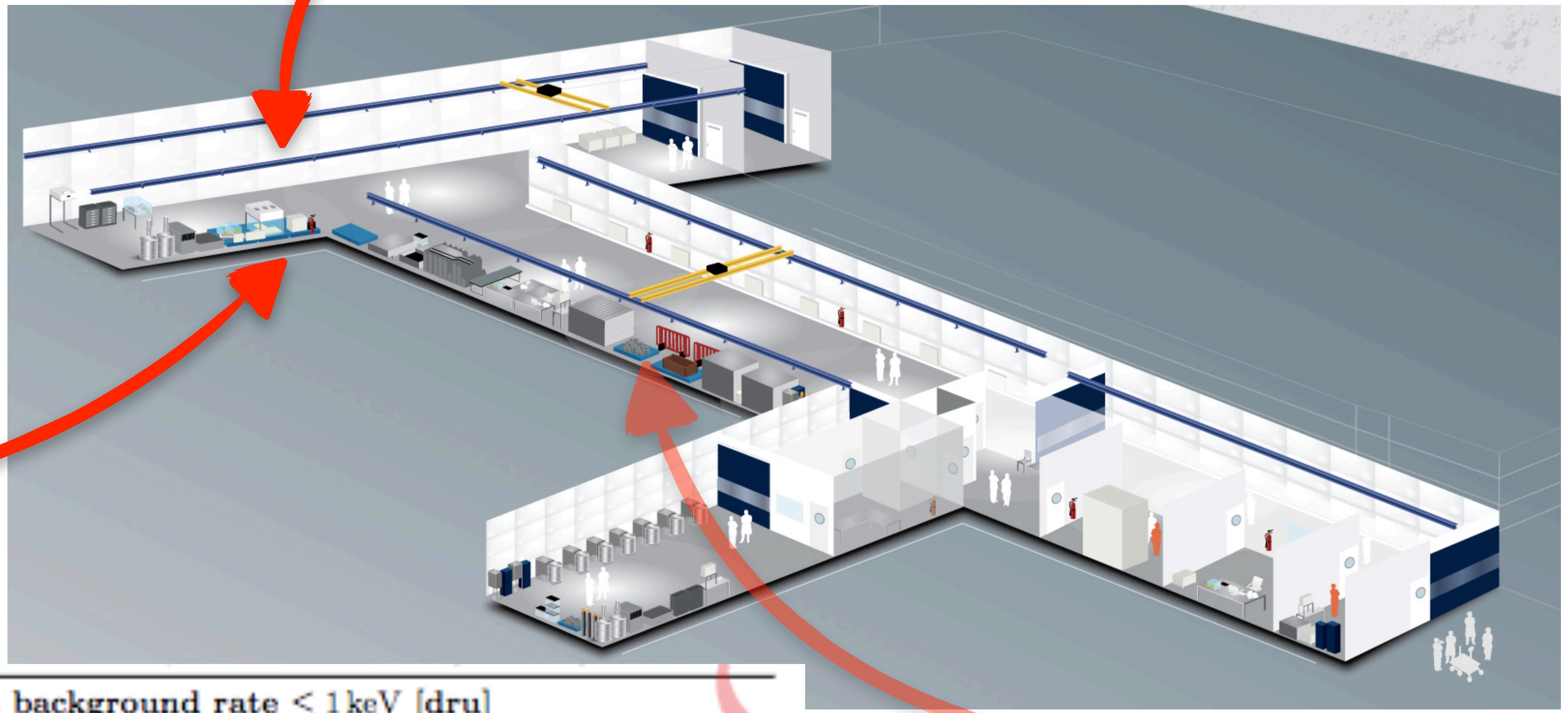
- Combination of W-value and Comimac QF used
  - Use conservative logarithmic extrapolation

Shielding & Backgrounds

- Available space in Boulby LEC: 8 x 8 x 8 m^3
- Conceptual shielding extensively studied in Geant4 with `G4RadioactiveDecayPhysics`
  - Several designs explored
- Found water-only achieves desired BG suppression
  - Dominant background is from photons from cavern
- Shielding material and copper (~10^{-5}dru) contributions are subdominant

Large Experimental Cavern (LEC)



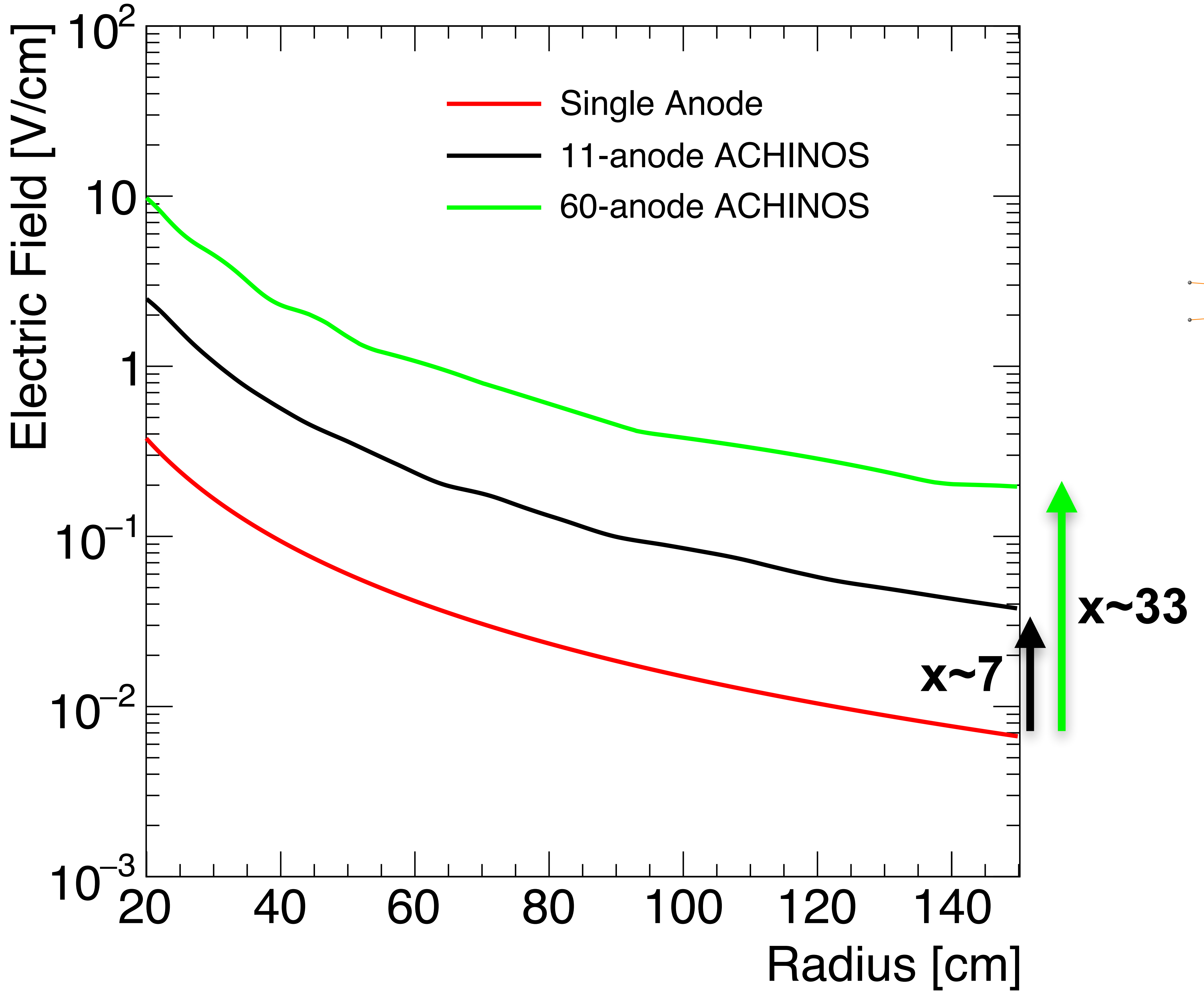


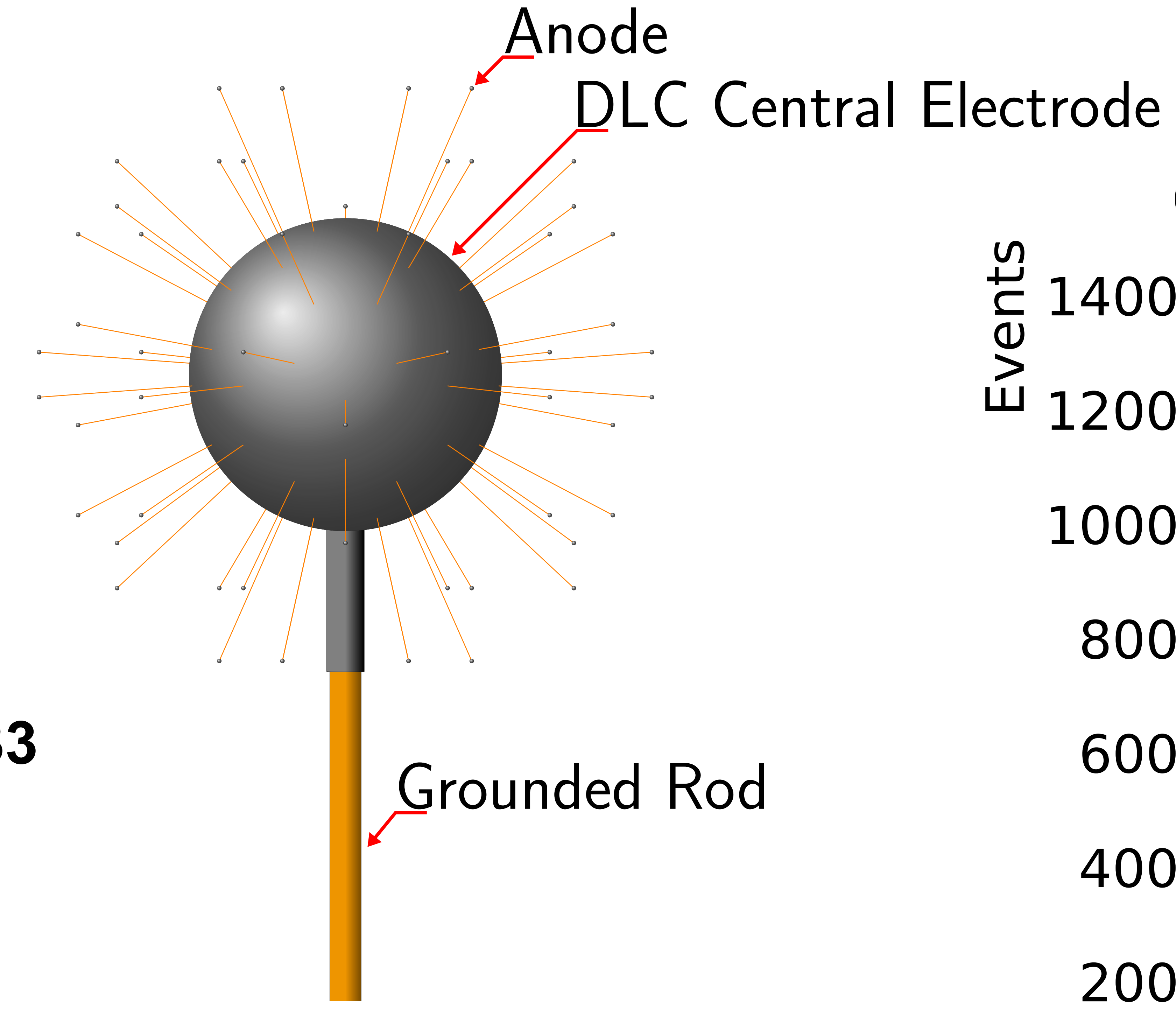
Shielding Configuration	Environmental background rate $\leq 1\,\mathrm{keV}$ [dru]			
	Photon-induced	Neutron-induced		
	Photon	Neutron	Photon	Total
2.5 m water	4.24×10^{-3} (0.06)	9.45×10^{-5} (0.54)	1.26×10^{-4} (0.31)	4.46×10^{-3} (0.06)

Current ⌀30cm SPC!

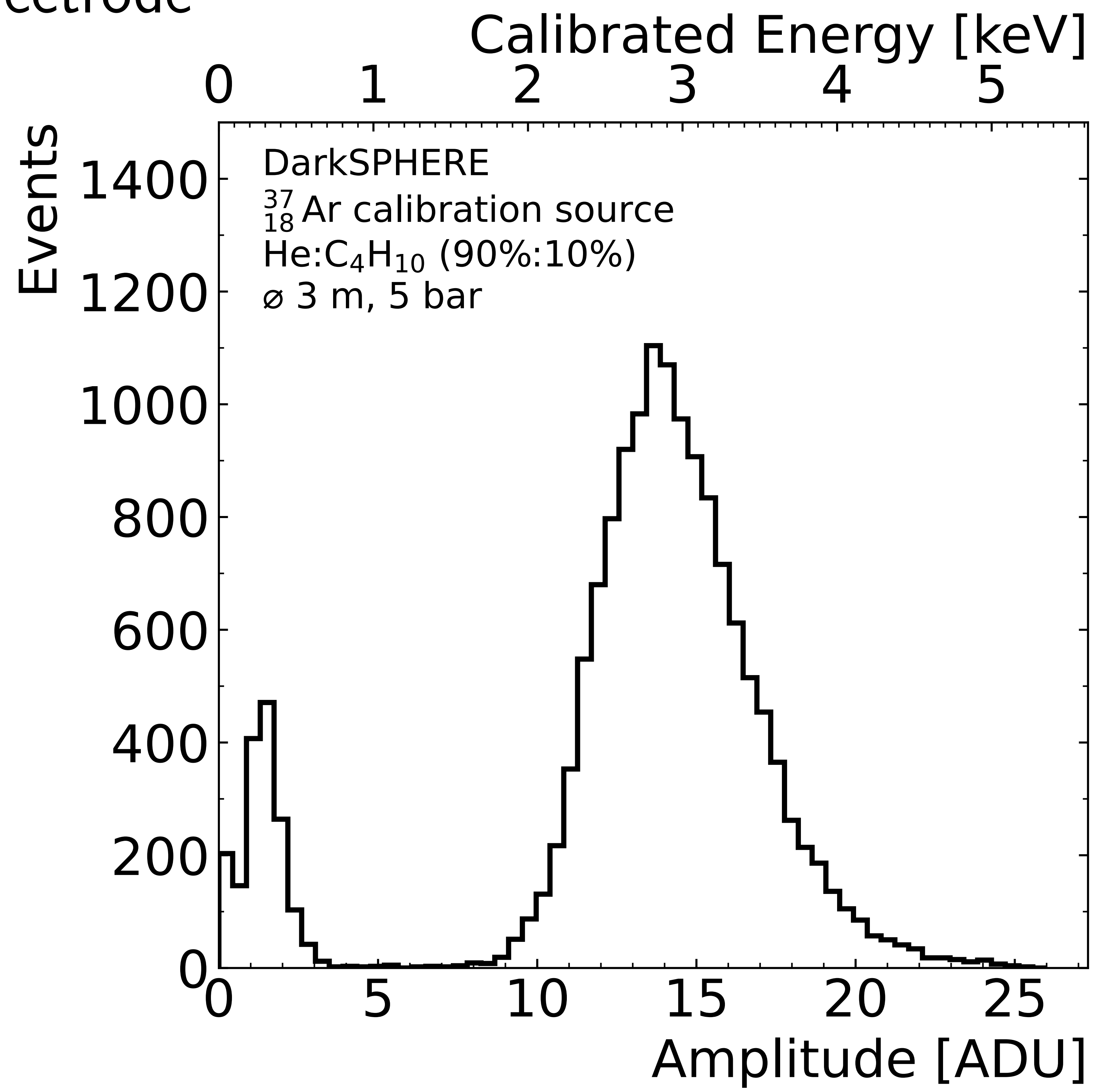
Read-Out and Calibration

- Larger detector requires larger ACHINOS
- First simulations performed with crude 60-anode ACHINOS
  - Anodes at vertices of truncated icosahedron (a football)
  - Use full simulation framework
- Also intend use laser calibration in DarkSPHERE

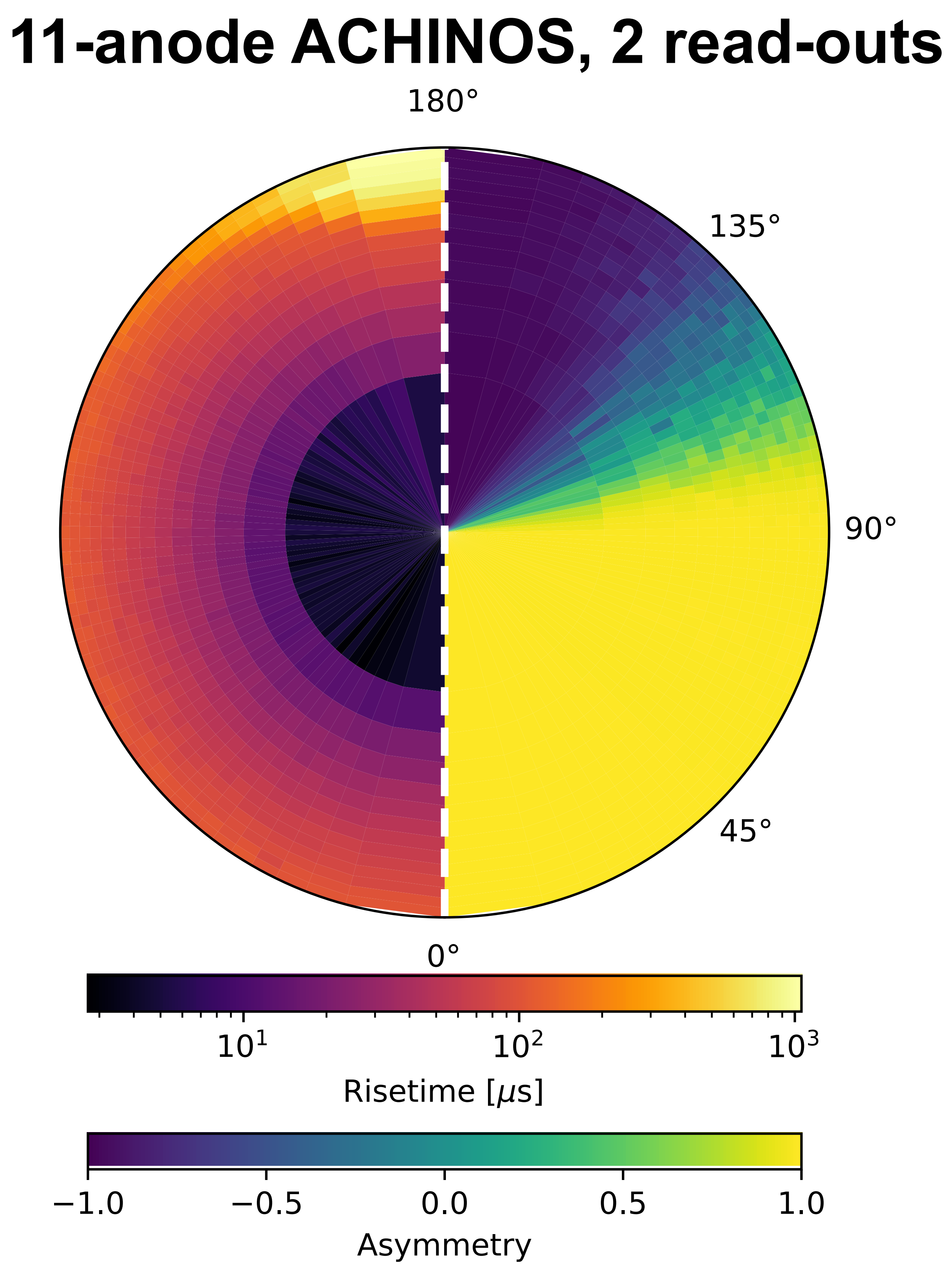


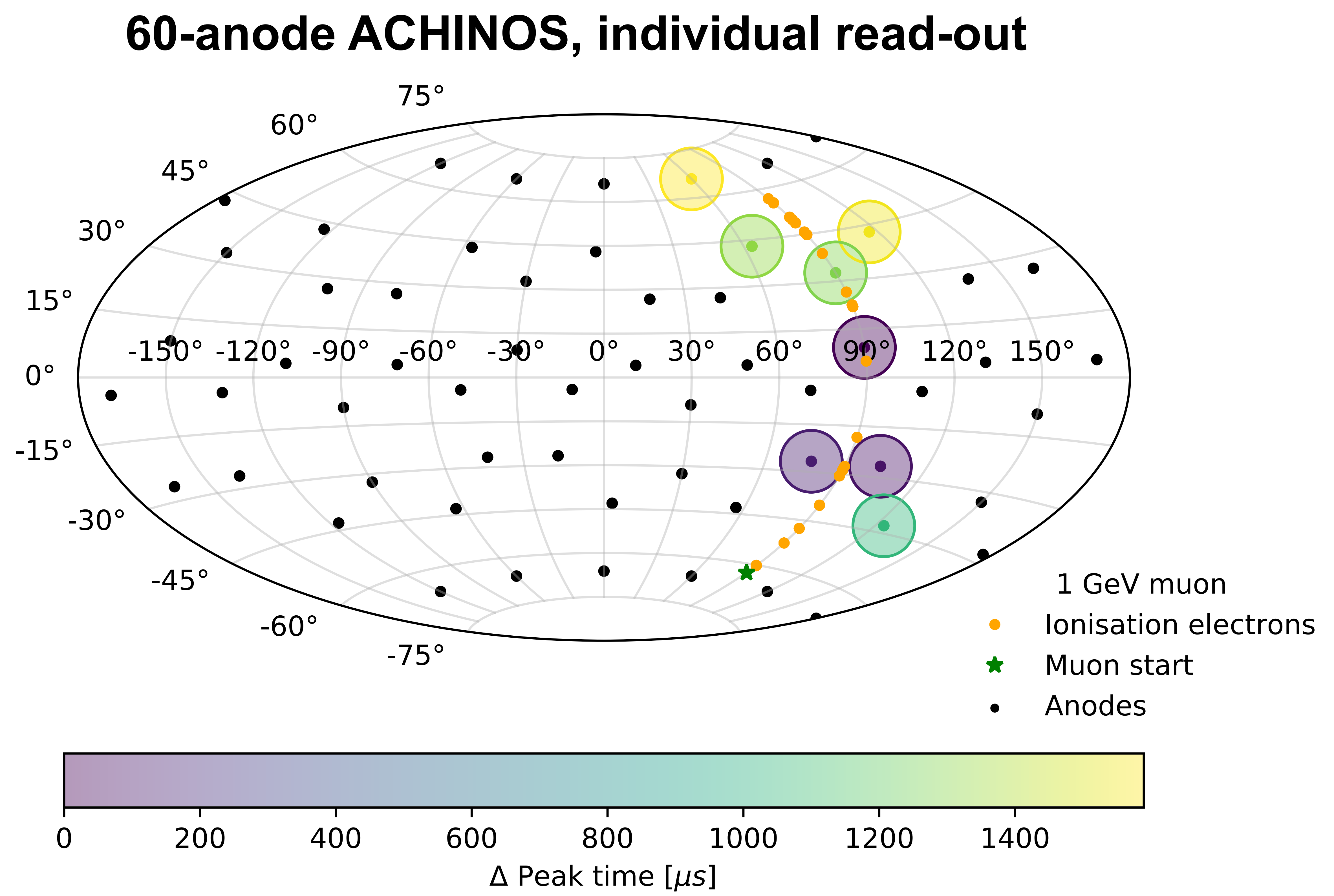


Simulation of ^{37}Ar Calibration



Event Localisation

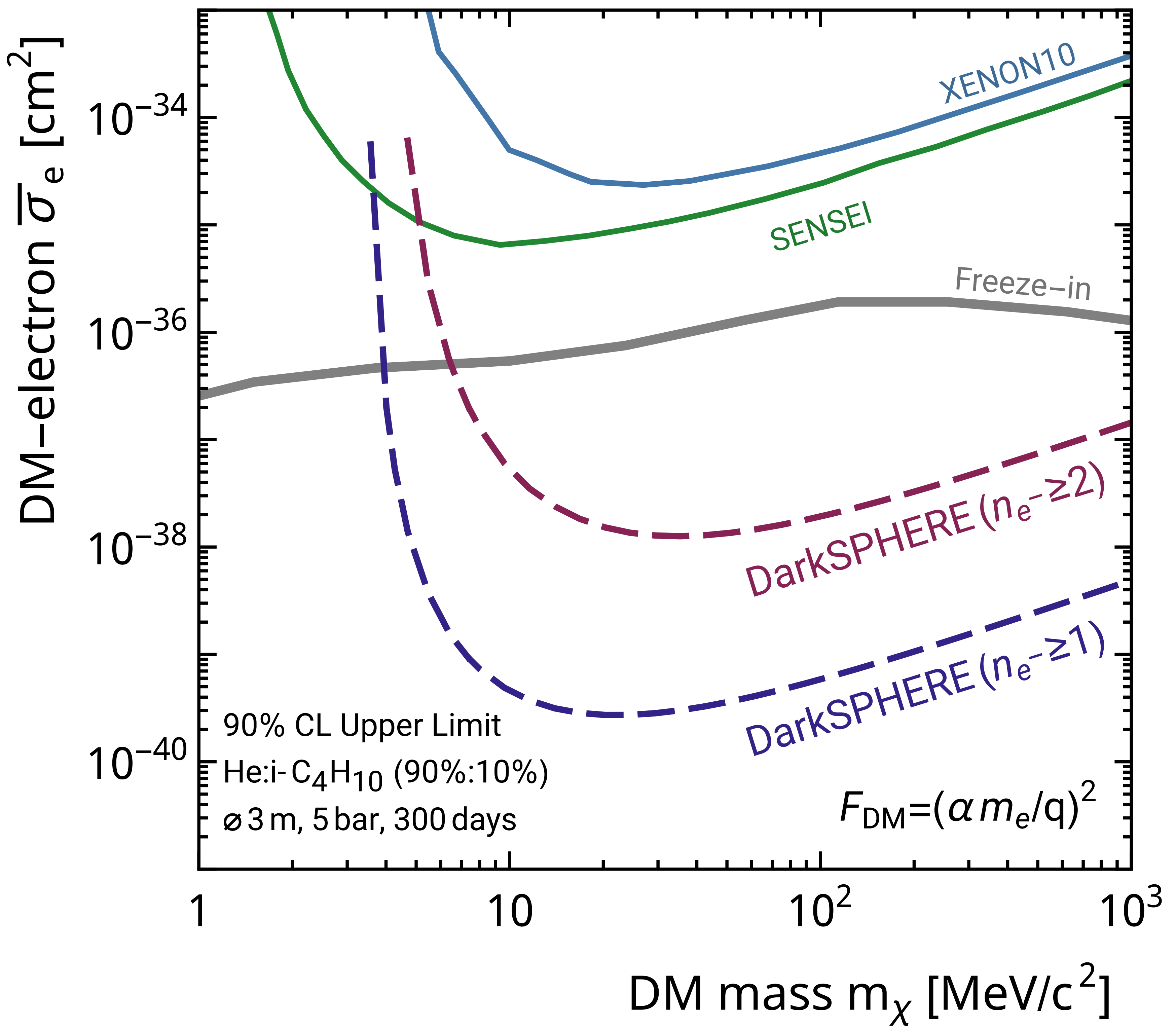


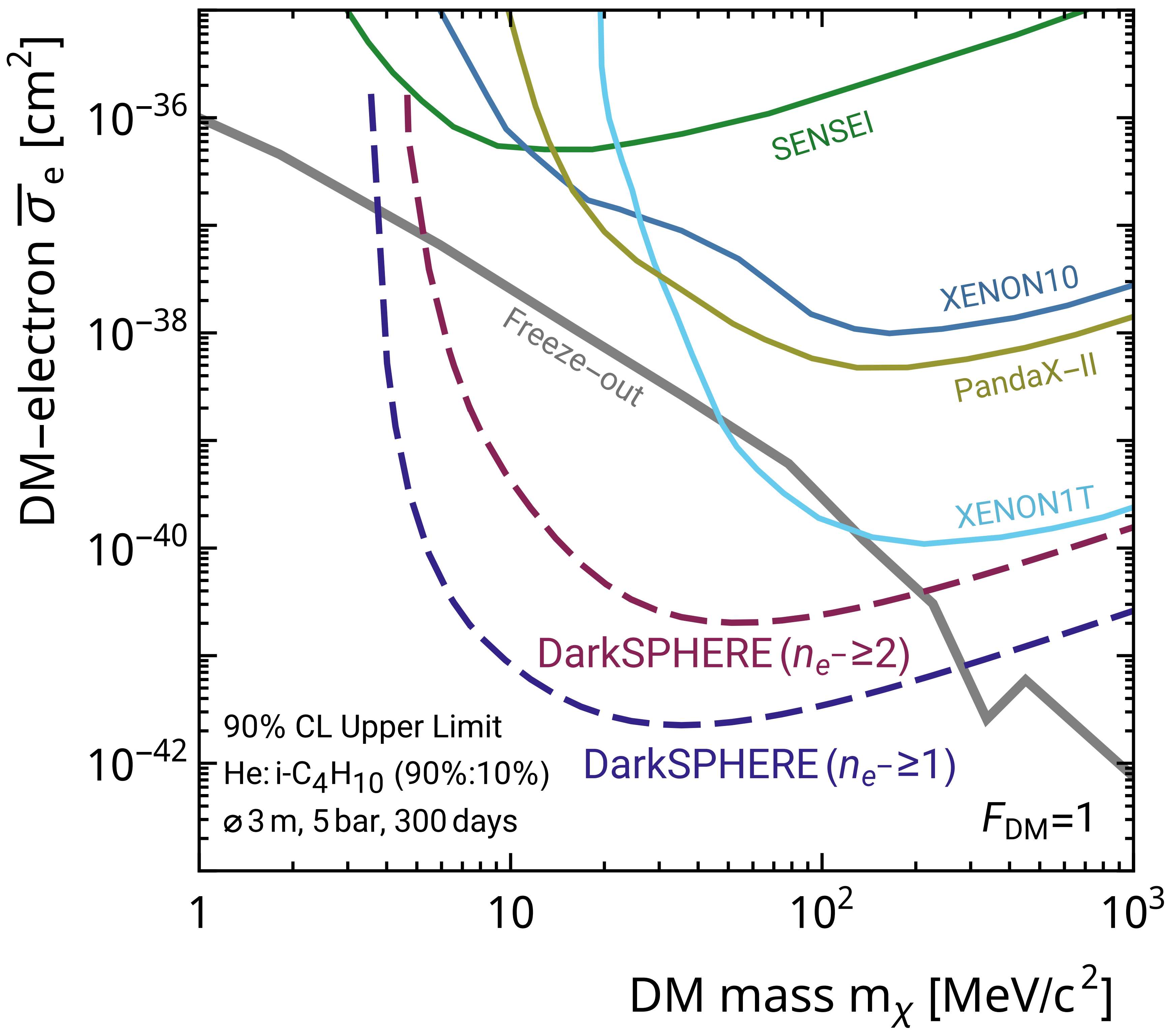


- Currently exploring event localisation capability of higher-anode achinos in simulation
- Provide additional BG rejection handles (track/point-like, position dependent etc.)

Nuclear-Recoil DM Searches

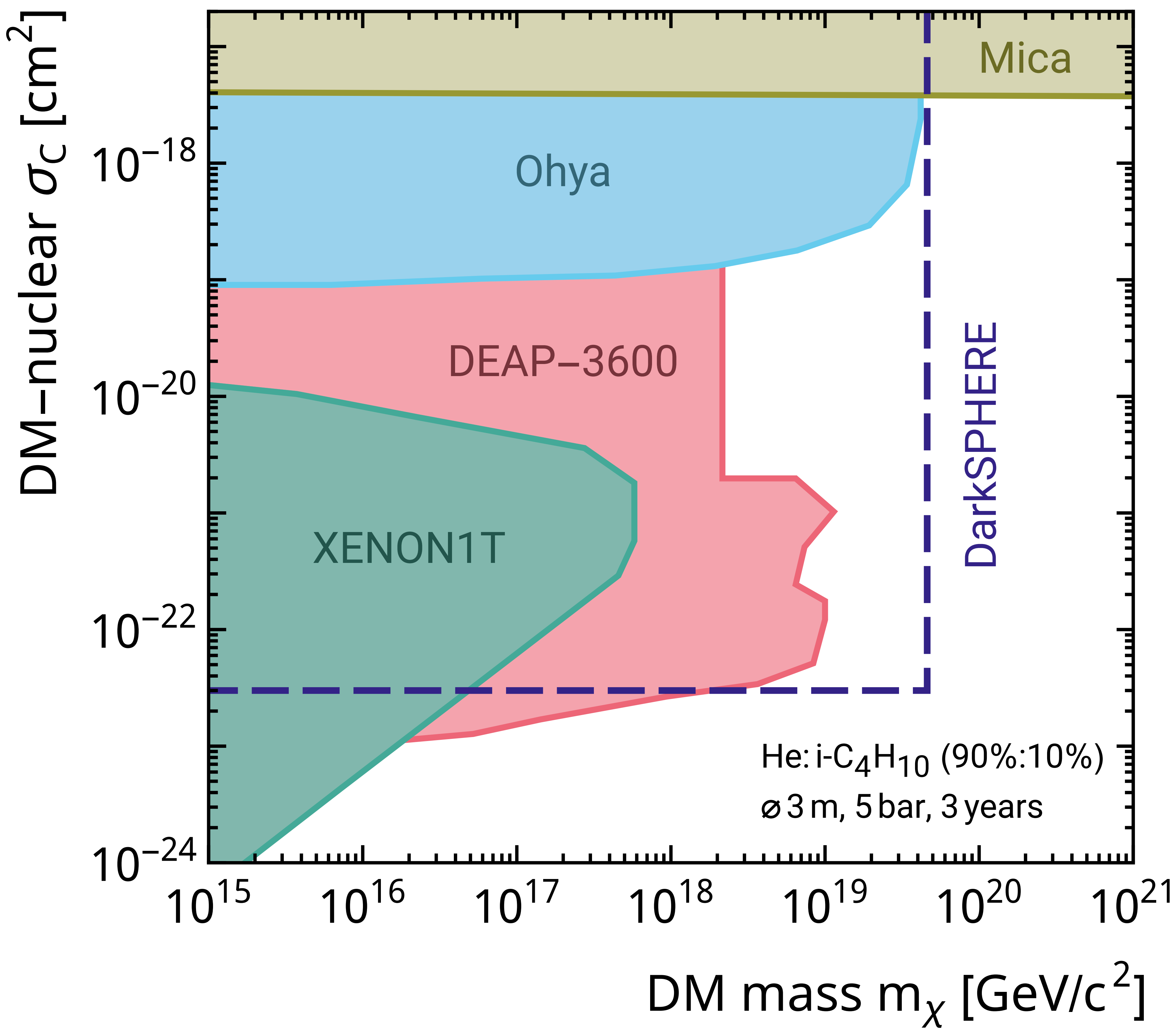
Electron-Recoil DM Searches





Heavy DM Searches and Other Applications

- Looking for multiply interacting DM in the detector
  - Sensitivity scales with detector radius
- Potential for a multi-physics platform:
  - 0νββ (R2D2)
  - ^{136}Xe at 5 bar in DarkSPHERE would detect ~ 5×(10 kpc/d_{SN})^2 events for supernova at distance d_{SN}, assuming a 27$M_\odot$ progenitor [C McCabe, L. Hamaide]

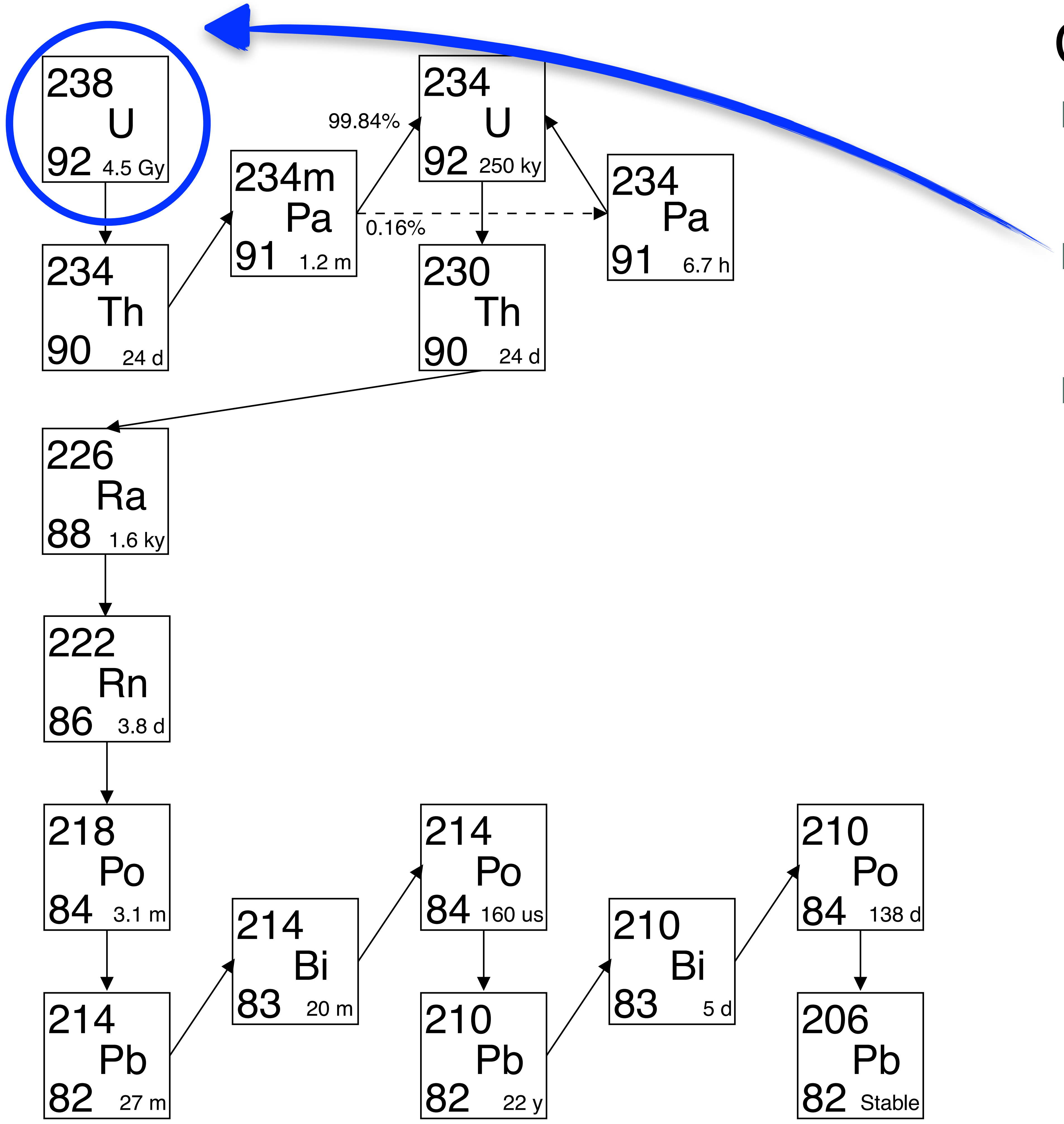


Boulby Electroforming Facility

- STFC Early Technology Development Capital Funding bid to establish deep-underground EFCu facility in Boulby successful
- Modelled after ECuME facility
  - Input from NEWS-G and PNNL
- Delivery of components ongoing!
- Boulby acquiring Type1 water facility

Unfortunately, just 4N5 Cu rods, not dark matter

Copper Backgrounds

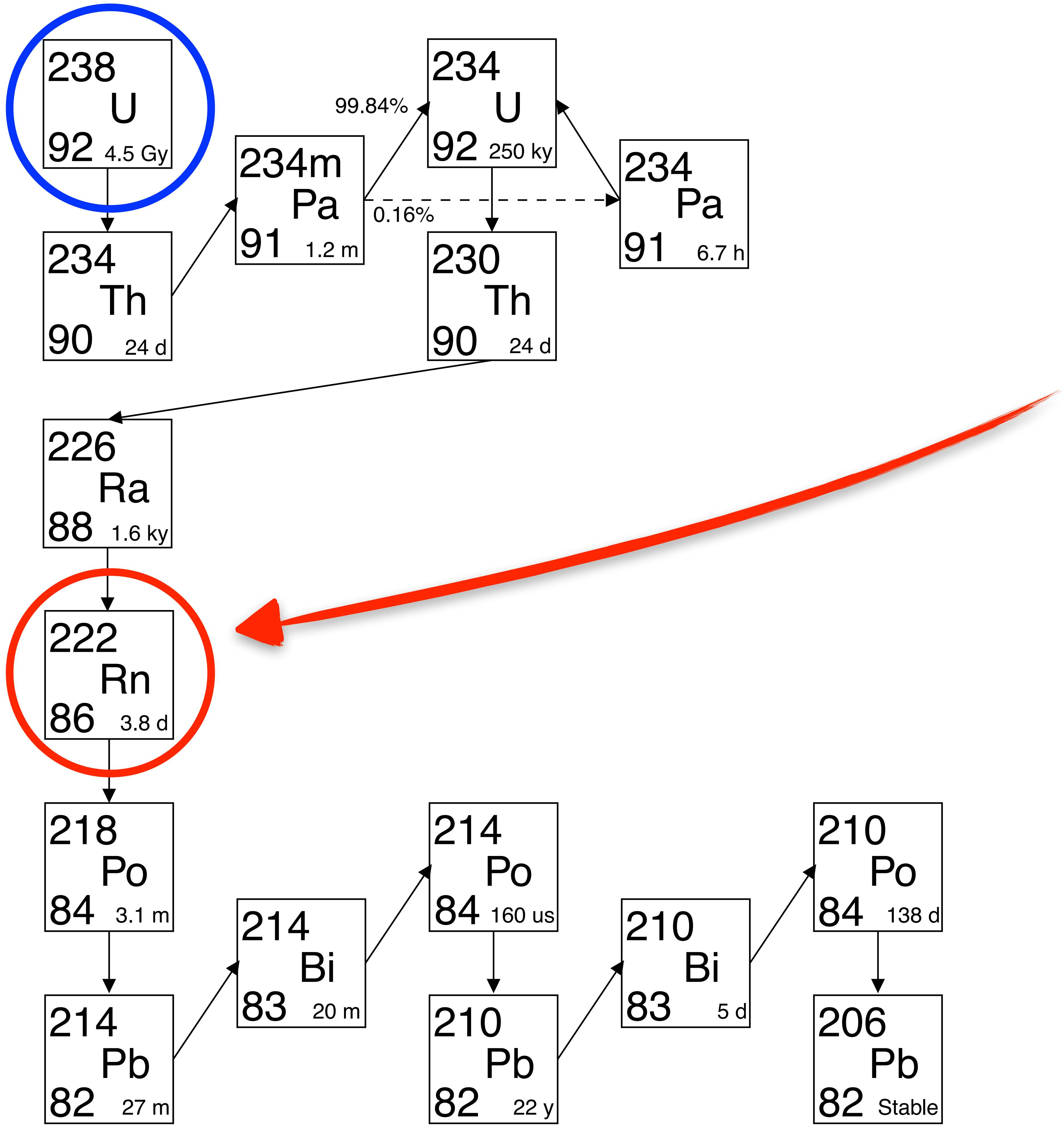


Commercial copper has two primary contamination sources:

- Fast neutrons from cosmic muon spallation e.g. $^{63}Cu(n,\alpha)^{60}Co$
  - Mitigation: minimise time outside underground laboratory
- **^{238}U and ^{232}Th** decay chains naturally found in raw material
  - Assay: ICP-MS ~10 µBq/kg
- Long-lived ^{238}**U** daughters introduced by ^{222}**Rn gas**
  - **^{210}Pb is long-lived**, so builds up, and leads to **break in secular equilibrium** of chain
  - Assay: alpha-counter, UltraLo-1800 ~30 mBq/kg

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

Copper Backgrounds

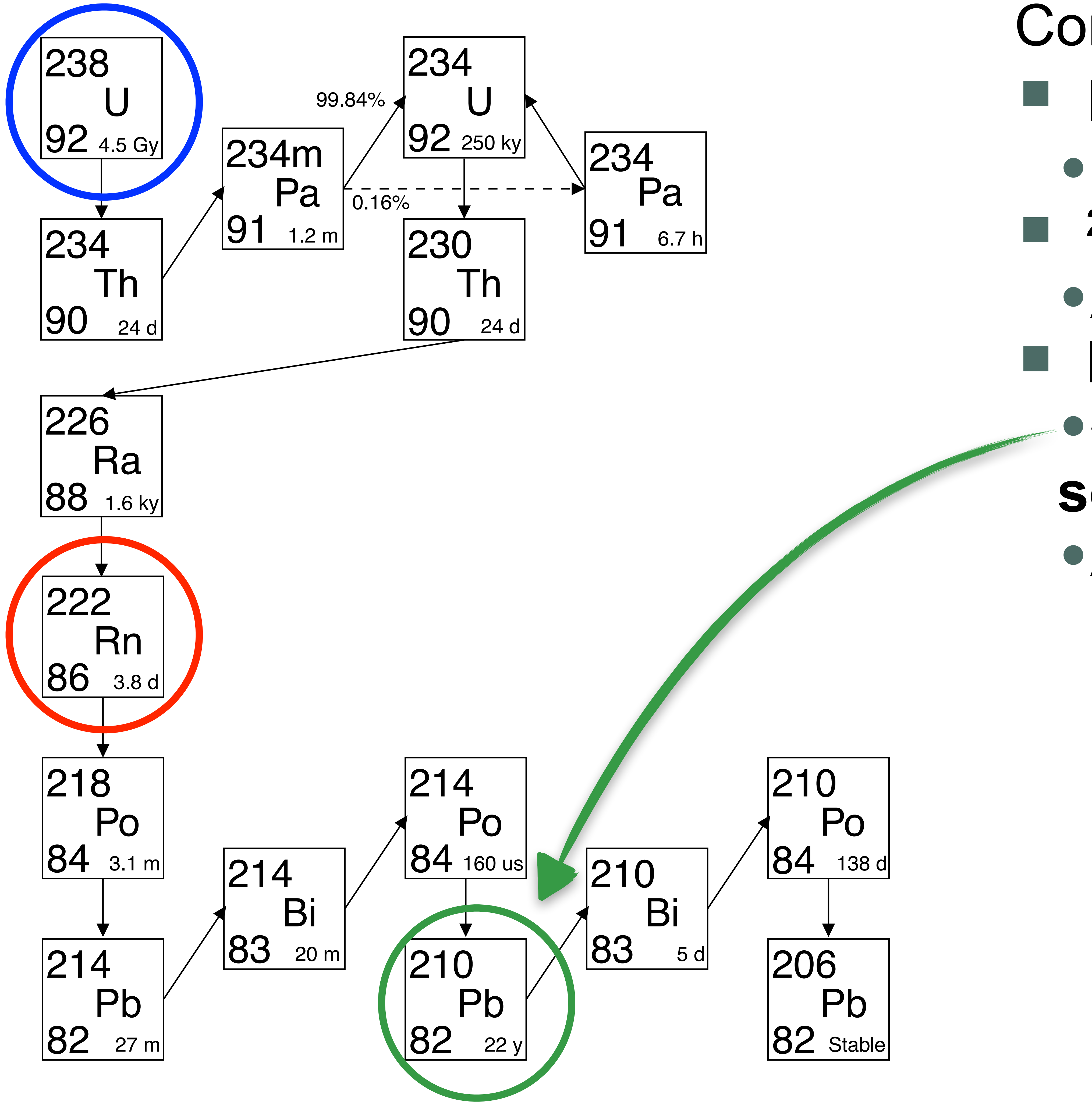


Commercial copper has two primary contamination sources:

- Fast neutrons from cosmic muon spallation e.g. ^{63}Cu(n,α)^{60}Co
  - Mitigation: minimise time outside underground laboratory
- **^{238}U and ^{232}Th** decay chains naturally found in raw material
  - Assay: ICP-MS ~10 μBq/kg
- Long-lived **^{238}U** daughters introduced by **^{222}Rn gas**
  - **^{210}Pb is long-lived**, so builds up, and leads to **break in secular equilibrium** of chain
  - Assay: alpha-counter, UltraLo-1800 ~30 mBq/kg

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

Copper Backgrounds

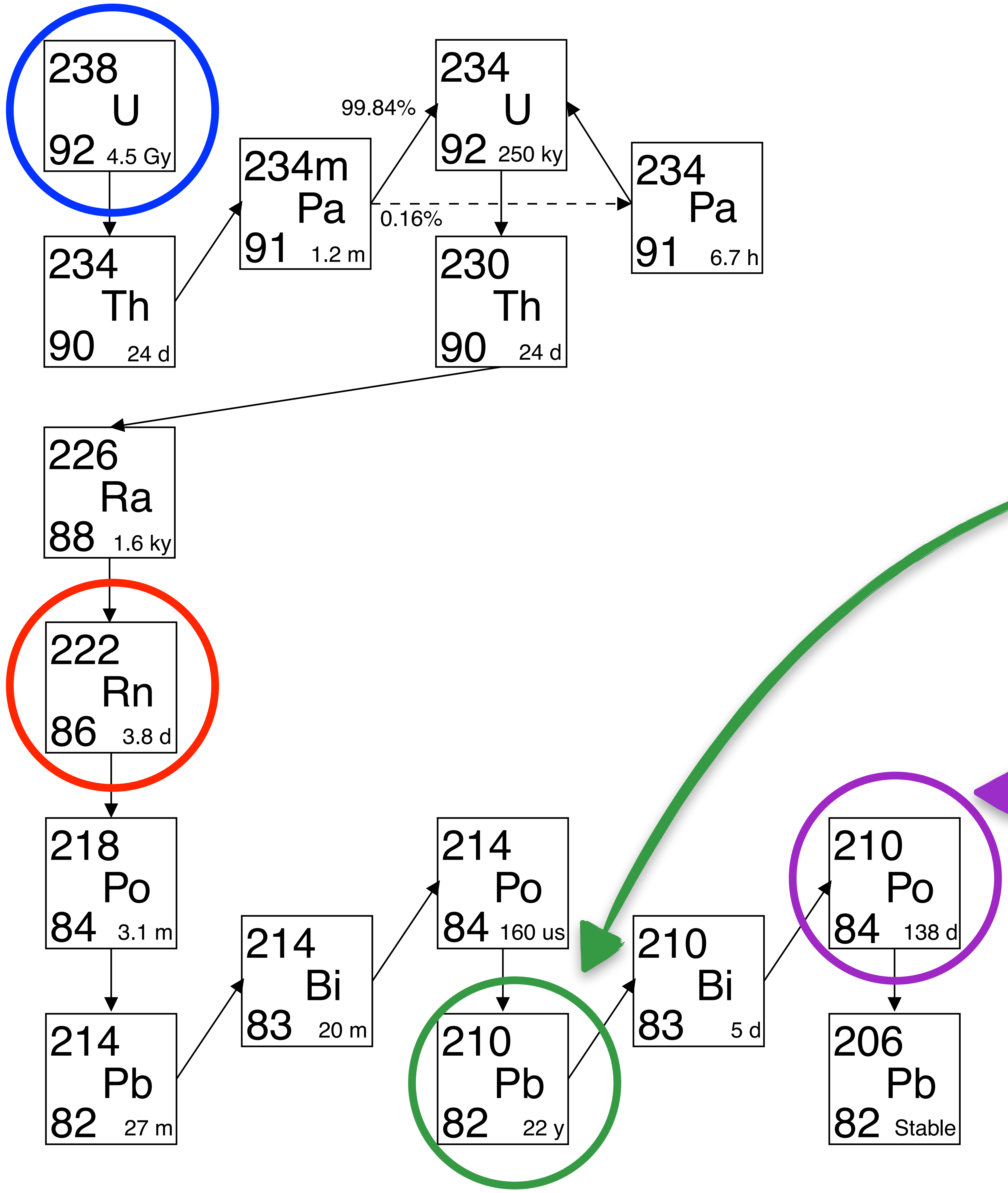


Commercial copper has two primary contamination sources:

- Fast neutrons from cosmic muon spallation e.g. $^{63}Cu(n,\alpha)^{60}Co$
  - Mitigation: minimise time outside underground laboratory
- **^{238}U and ^{232}Th** decay chains naturally found in raw material
  - Assay: ICP-MS ~10 μBq/kg
- Long-lived ^{238}**U** daughters introduced by **^{222}Rn gas**
  - **^{210}Pb is long-lived**, so builds up, and leads to **break in secular equilibrium** of chain
  - Assay: alpha-counter, UltraLo-1800 ~30 mBq/kg

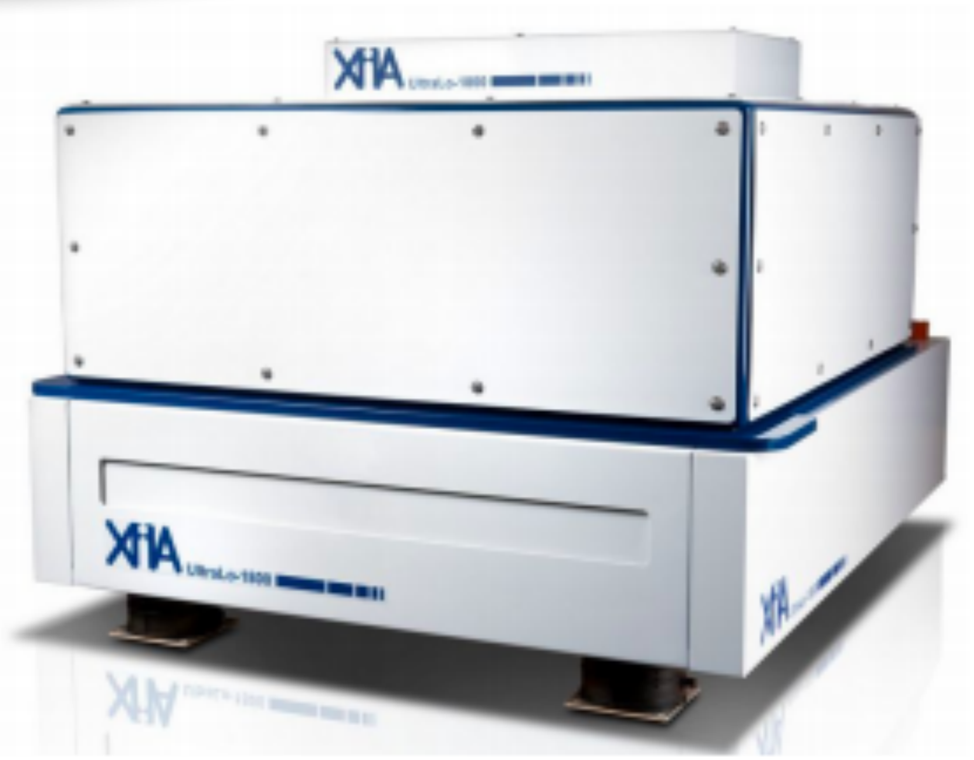
XIA UltraLo-1800
https://www.xia.com/ultralo-theory.html

Copper Backgrounds



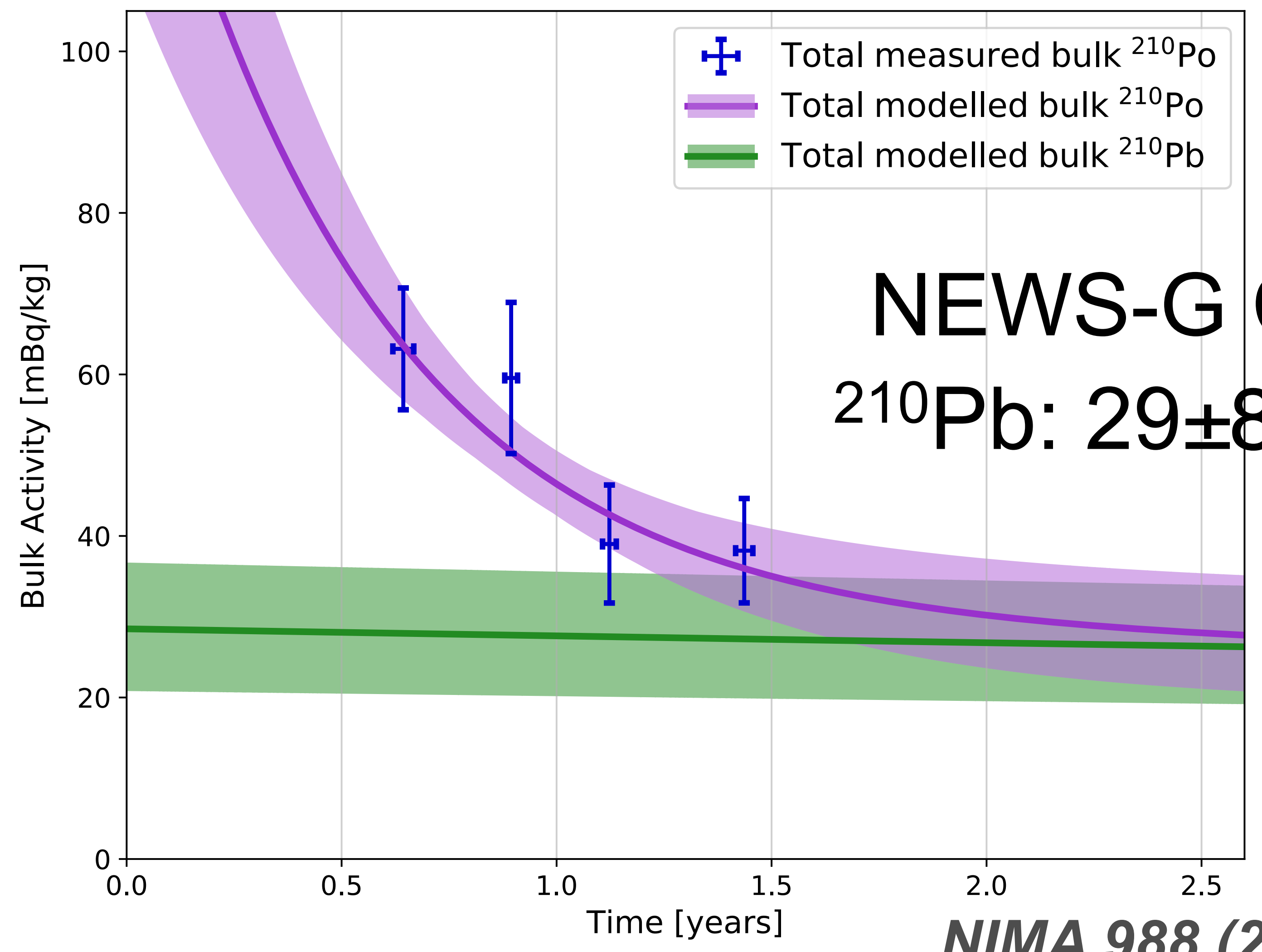
Commercial copper has two primary contamination sources:

- Fast neutrons from cosmic muon spallation e.g. $^{63}Cu(n,\alpha)^{60}Co$
  - Mitigation: minimise time outside underground laboratory
- **^{238}U and ^{232}Th** decay chains naturally found in raw material
  - Assay: ICP-MS ~10 µBq/kg
- Long-lived **^{238}U** daughters introduced by **^{222}Rn gas**
  - **^{210}Pb is long-lived**, so builds up, and leads to **break in secular equilibrium** of chain
  - Assay: alpha-counter, UltraLo-1800 ~30 mBq/kg



XIA UltraLo-1800

https://www.xia.com/ultralo-theory.html



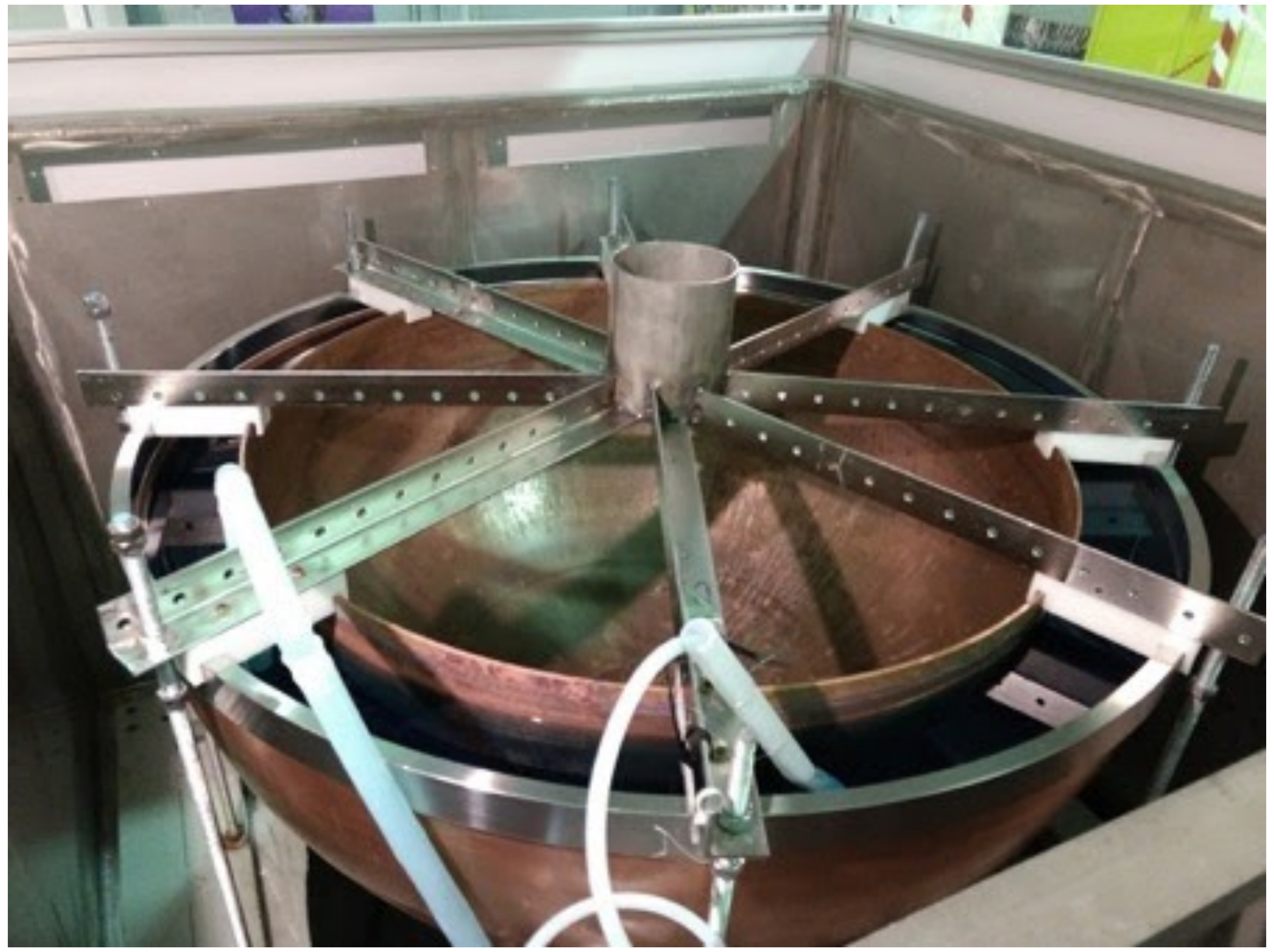
NEWS-G Copper:

^{210}Pb: 29±8 mBq/kg

NIMA 988 (2021) 164844

Ultra-Pure Copper Electroplating

- Exploits electrochemical properties
  - **Cu Preferentially deposited**
- **500 μm electroplated layer** on detector inner surface
- **Background reduction** by factor 2.6 <1 keV (Geant4)
- Copper deposition rate **~36 μm/day**
  - Could electroform complete detector
- **ICP-MS assay** of sample comparable to other EF copper
  - ^{210}Po in other EF copper below XIA UltraLo-1800 sensitivity <3 mBq/kg



Ultra-Pure Copper Electroplating

- Exploits electrochemical properties
  - **Cu Preferentially deposited**
- **500 µm electroplated layer** on detector inner surface
- **Background reduction** by factor 2.6 <1 keV (Geant4)
- Copper deposition rate **~36 µm/day**
  - Could electroform complete detector
- **ICP-MS assay** of sample comparable to other EF copper
  - ^{210}Po in other EF copper below XIA UltraLo-1800 sensitivity <3 mBq/kg

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

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

Contents lists available at ScienceDirect

ELSEVIER

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

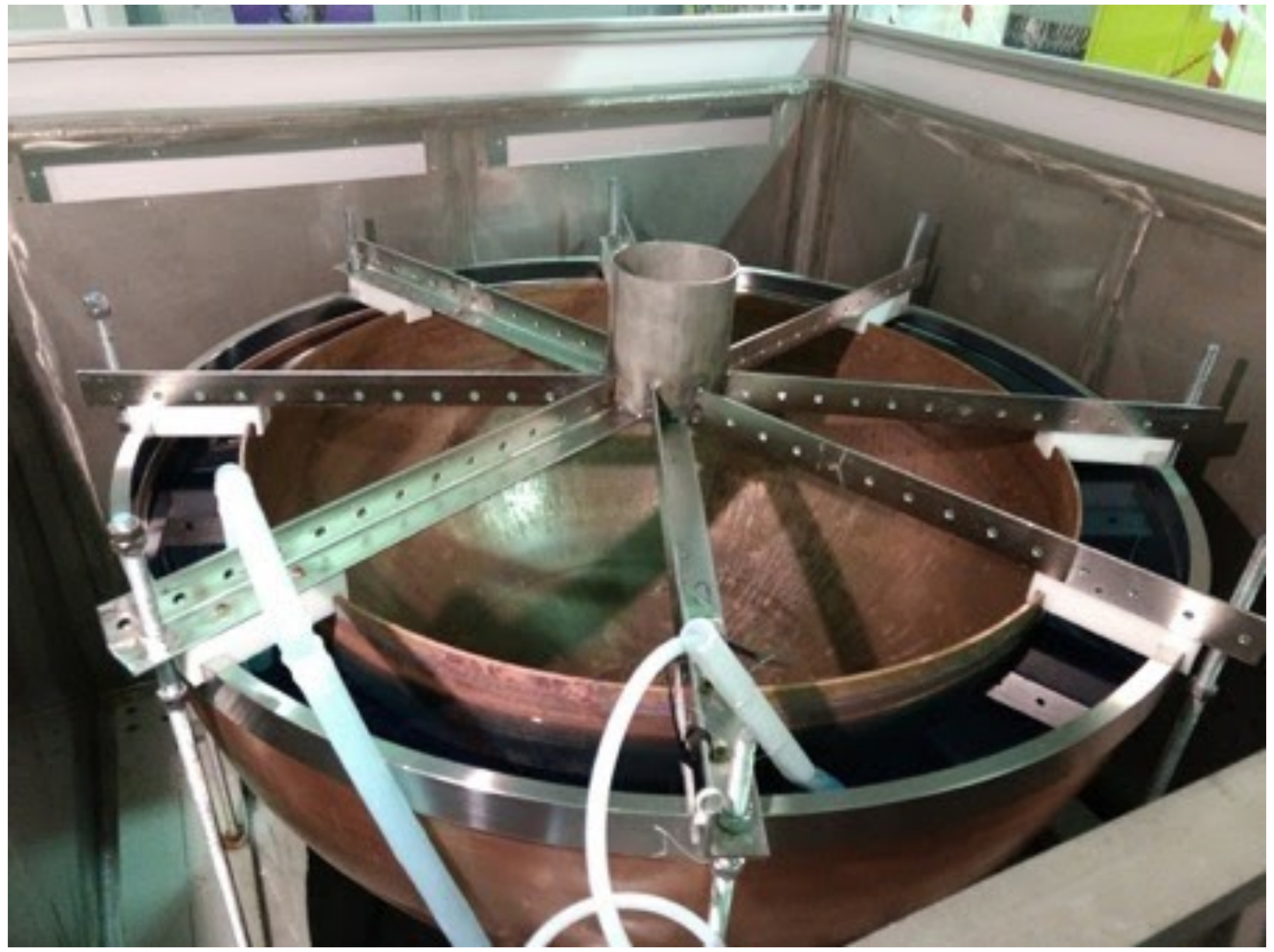
L. Balogh [a], C. Beaufort [b], A. Brossard [a], R. Bunker [c], J.-F. Caron [a], M. Chapellier [a], J.-M. Coquillat [a], E.C. Corcoran [d], S. Crawford [a], A. Dastgheibi Fard [b], Y. Deng [e], K. Dering [a], D. Durnford [e], G. Gerbier [a], I. Giomataris [f], G. Giroux [a], P. Gorel [g,h,i], M. Gros [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 [f], 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]

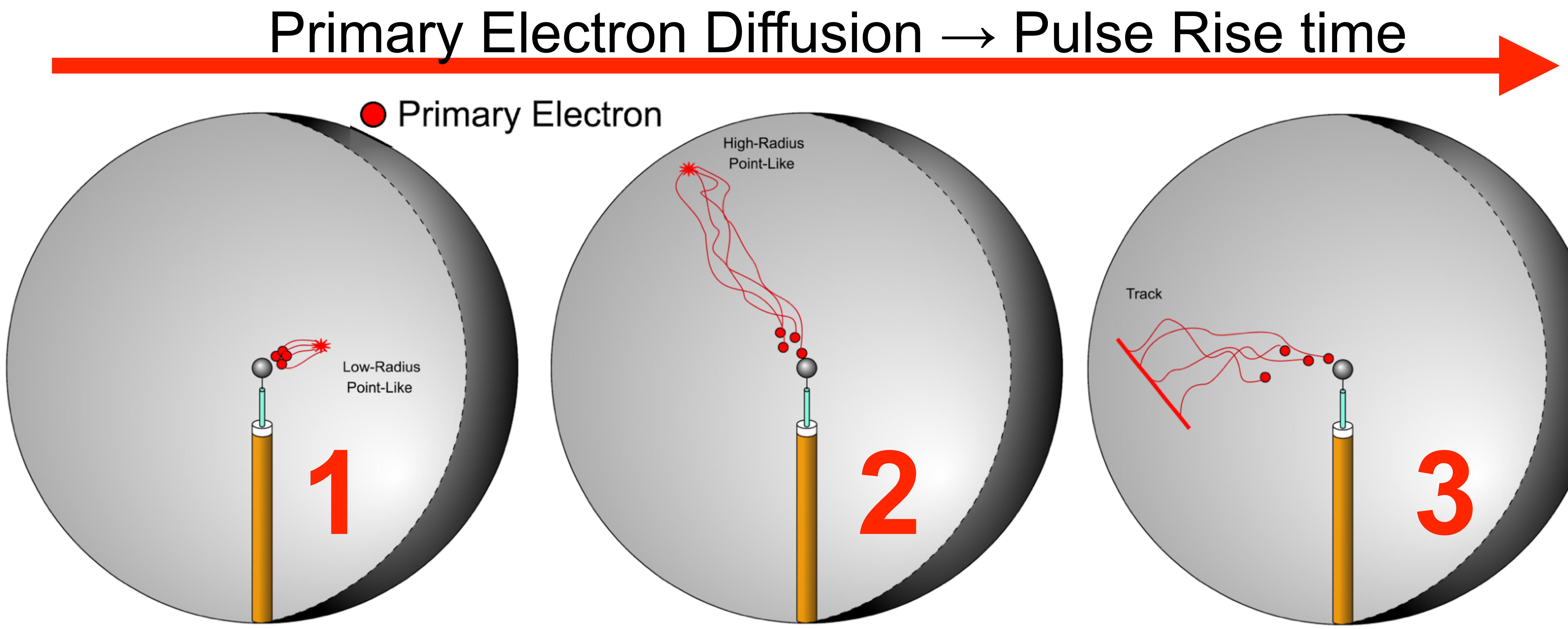
[a] Department of Physics, Engineering Physics & Astronomy, Queen's University, Kingston, Ontario K7L 3N6, Canada
[b] LPSC, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France
[c] Pacific Northwest National Laboratory, Richland, WA 99352, USA
[d] Chemistry & Chemical Engineering Department, Royal Military College of Canada, Kingston, Ontario K7K 7B4, Canada
[e] Department of Physics, University of Alberta, Edmonton, Alberta, T6G 2R3, Canada
[f] IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[g] Department of Physics and Astronomy, Laurentian University, Sudbury, Ontario, P3E 2C6, Canada
[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

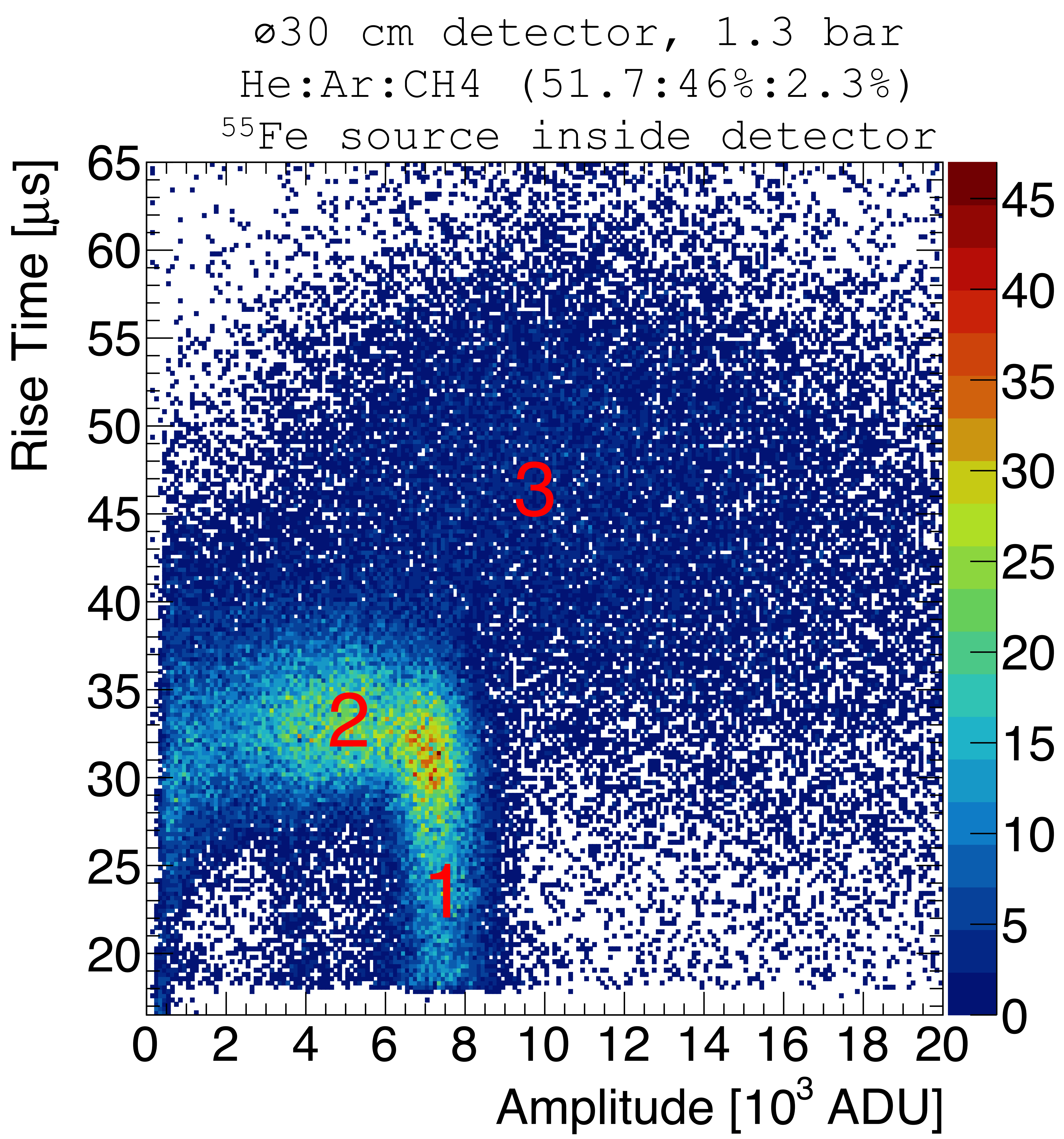
NIMA 988 (2021) 164844



Pulse-Shape Discrimination

- Lots of information in a pulse. e.g. in rise time
- Electron from **larger radii diffuse more**
  - Larger spread in arrival → higher pulse rise time/width
- Spatially extended primary ionisation results in higher rise time/width
- **Particle ID by pulse-shape discrimination** possible





(1) X-rays in volume, (2) X-rays near shell, (3) Cosmic muons

Background Contributions to SNOGLOBE

	Source	Contamination / flux	Unit	Events rate <1 keV [dru]	Events rate in [1;5] keV [dru]	Total rate [mHz]
Gas mixture	^{3}H	13	μBq/kg	0.05	0.06	0.005
	^{222}Rn	111	μBq/kg	0.05	0.04	0.2
Copper sphere 500 μm electrolyte	^{210}Pb	28.5	mBq/kg	1.04	1.01	0.86
	^{238}U	3	μBq/kg	0.0117	0.115	0.028
	^{232}Th	13	μBq/kg	0.0754	0.0692	0.163
	^{40}K	0.1	mBq/kg	0.0157	0.0186	0.0622
Roman lead	^{210}Pb	<25	mBq/kg	<0.14	<0.12	0.057
	^{238}U	44.5	μBq/kg	0.142	0.094	0.277
	^{232}Th	9.1	μBq/kg	0.0256	0.0161	0.0577
	^{40}K	<1.3	mBq/kg	<0.28	0.23	0.65
Low activity lead	^{210}Pb	4.6	Bq/kg	0.053	0.055	0.17
	^{238}U	79	μBq/kg	0.17	0.132	0.5
	^{232}Th	9	μBq/kg	0.0251	0.0201	0.075
	^{40}K	<1.46	mBq/kg	<0.35	0.26	0.67
Cavern	Gamma	4.87×10^{-8}	γ/cm^2/s	0.0084	0.0095	0.00464
	Neutron	4000	neutron/m^2/day	0.0044	0.0004	3.54×10^{-11}
	Muon	0.27	muon/m^2/day	0.00062	0.00044	5.04×10^{-8}
Total				1.67	1.54	2.4
Total + cosmogenic activation of the copper sphere				5.20	5.20	5.4
Total + cosmogenic activation of the copper sphere and 6 months of cooling				2.8	2.5	3.4
Total + cosmogenic activation of the copper sphere and 1 years of cooling				2.1	1.9	3.0
Total + cosmogenic activation of the copper sphere and 2 years of cooling				1.9	1.7	2.9

Table 5.6: Summary of the main background of NEWS-G at SNOLAB, without rise time selection. The upper limits of activities in the lead are not taking into account in the total.

From A. Brossard, Ph. D. Thesis