Status of the NEWS-G experiment

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University of Birmingham

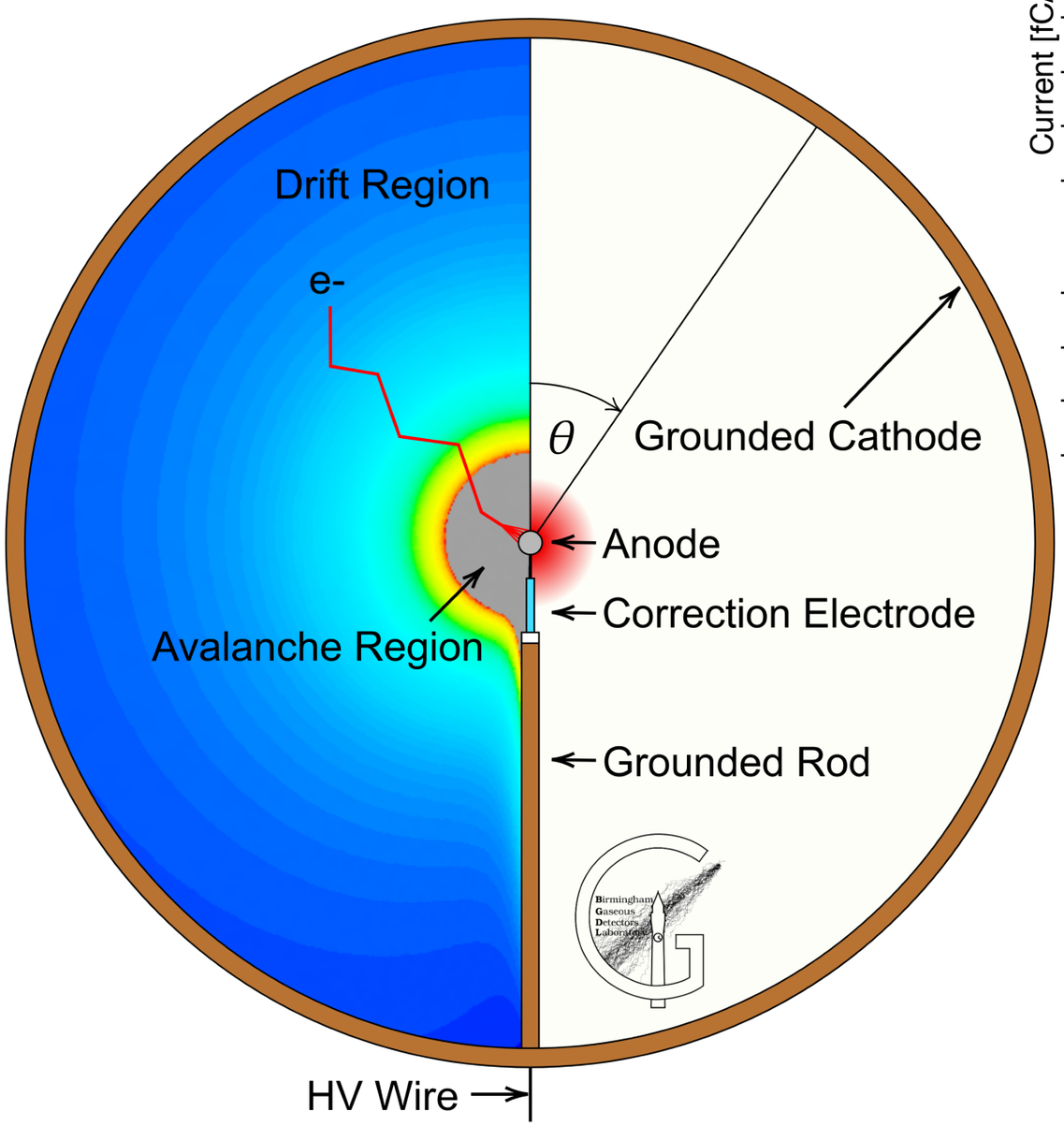
UNIVERSITY OF BIRMINGHAM

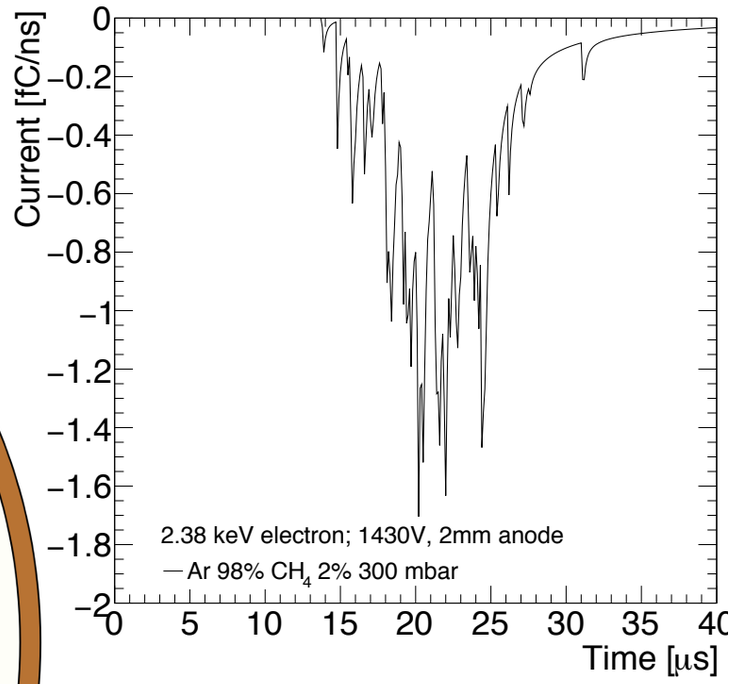
Dark Matter UK meeting
November 16th, 2021, Rutherford Appleton Laboratory, UK

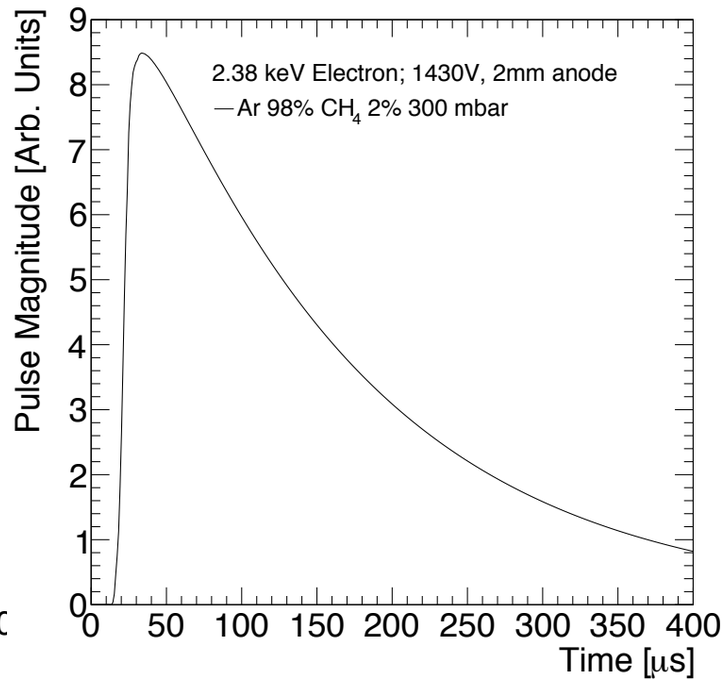
This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement 714893-ExclusiveHiggs and under Marie Skłodowska-Curie agreement 841261-DarkSphere, 895168-neutronSPHERE

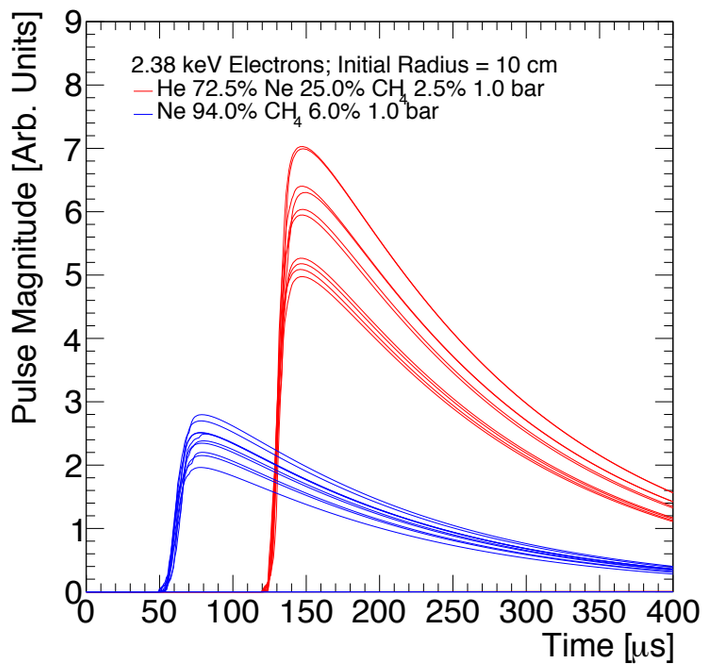
Spherical Proportional Counter

Electric field scales as $1/r^2$, volume divided in: "drift" and "amplification" regions
Capacitance independent of size: low electronic noise → single electron threshold

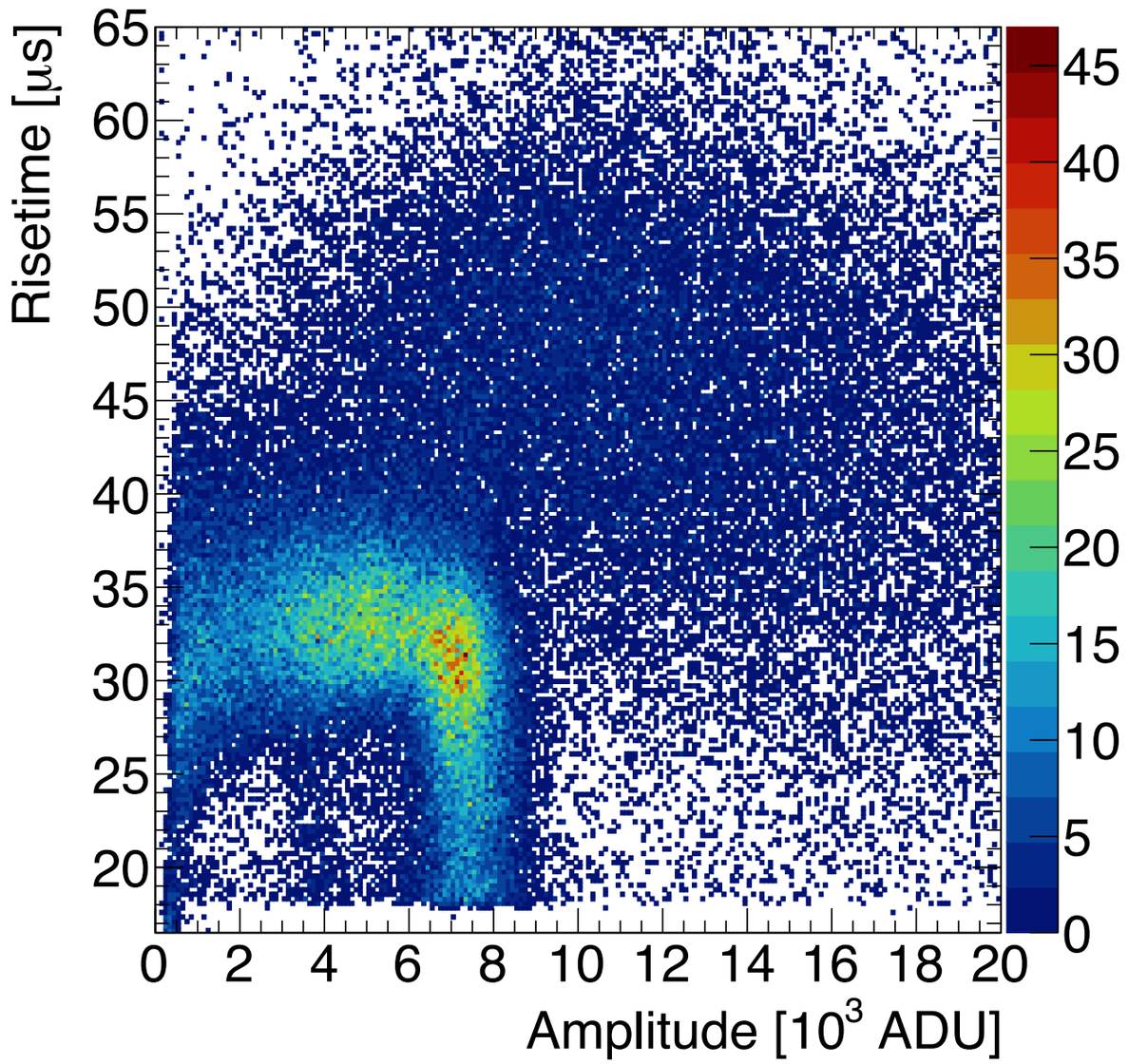




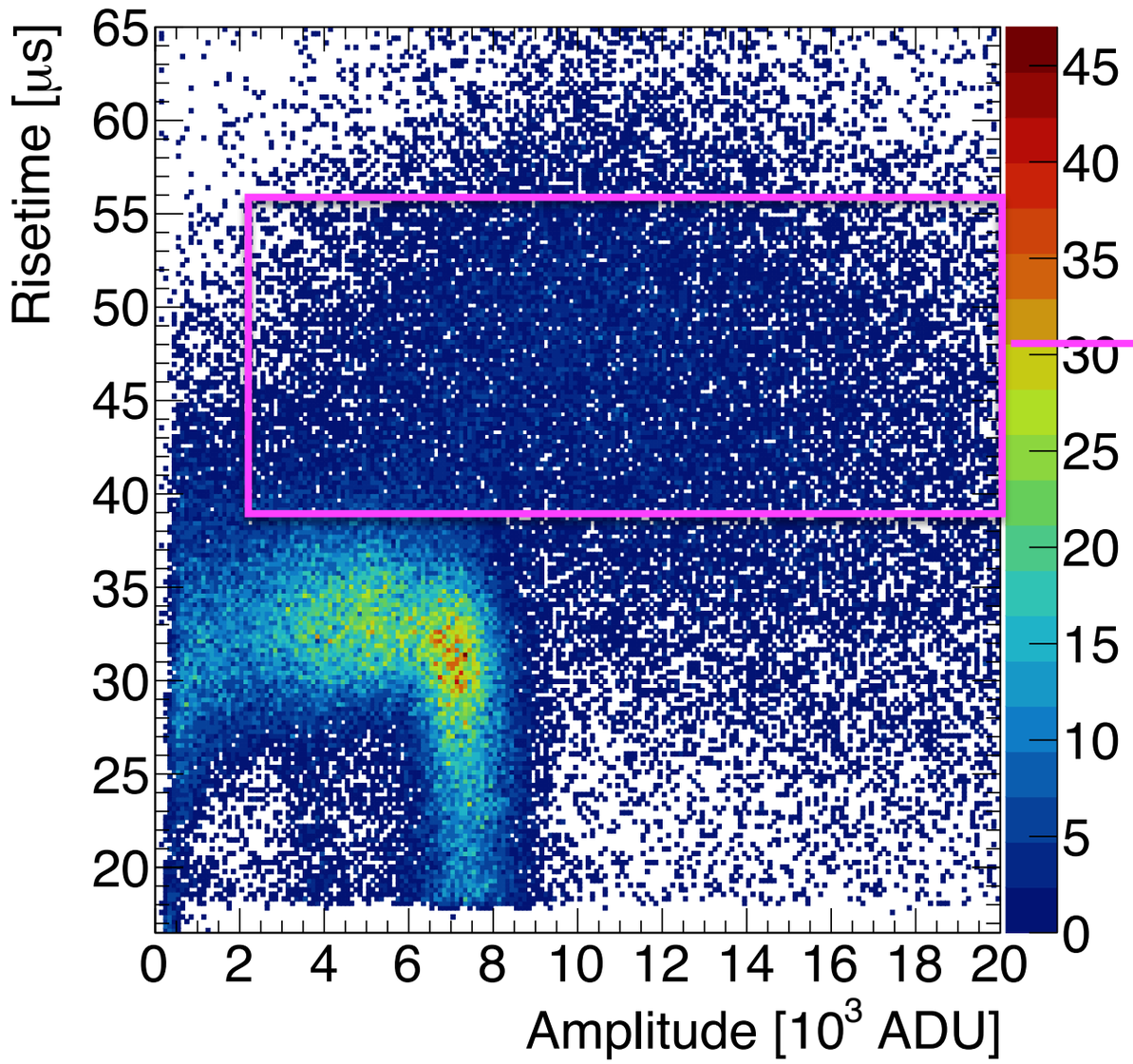


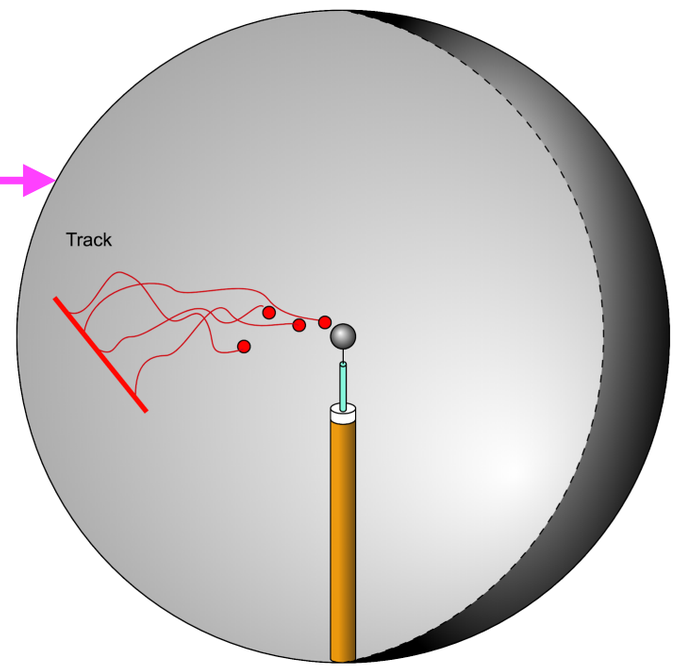


Pulse Shape Discrimination



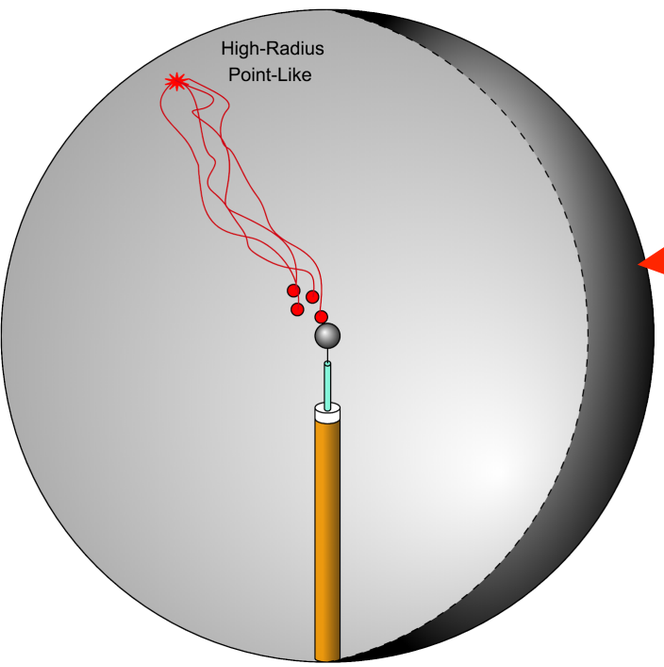
Pulse Shape Discrimination



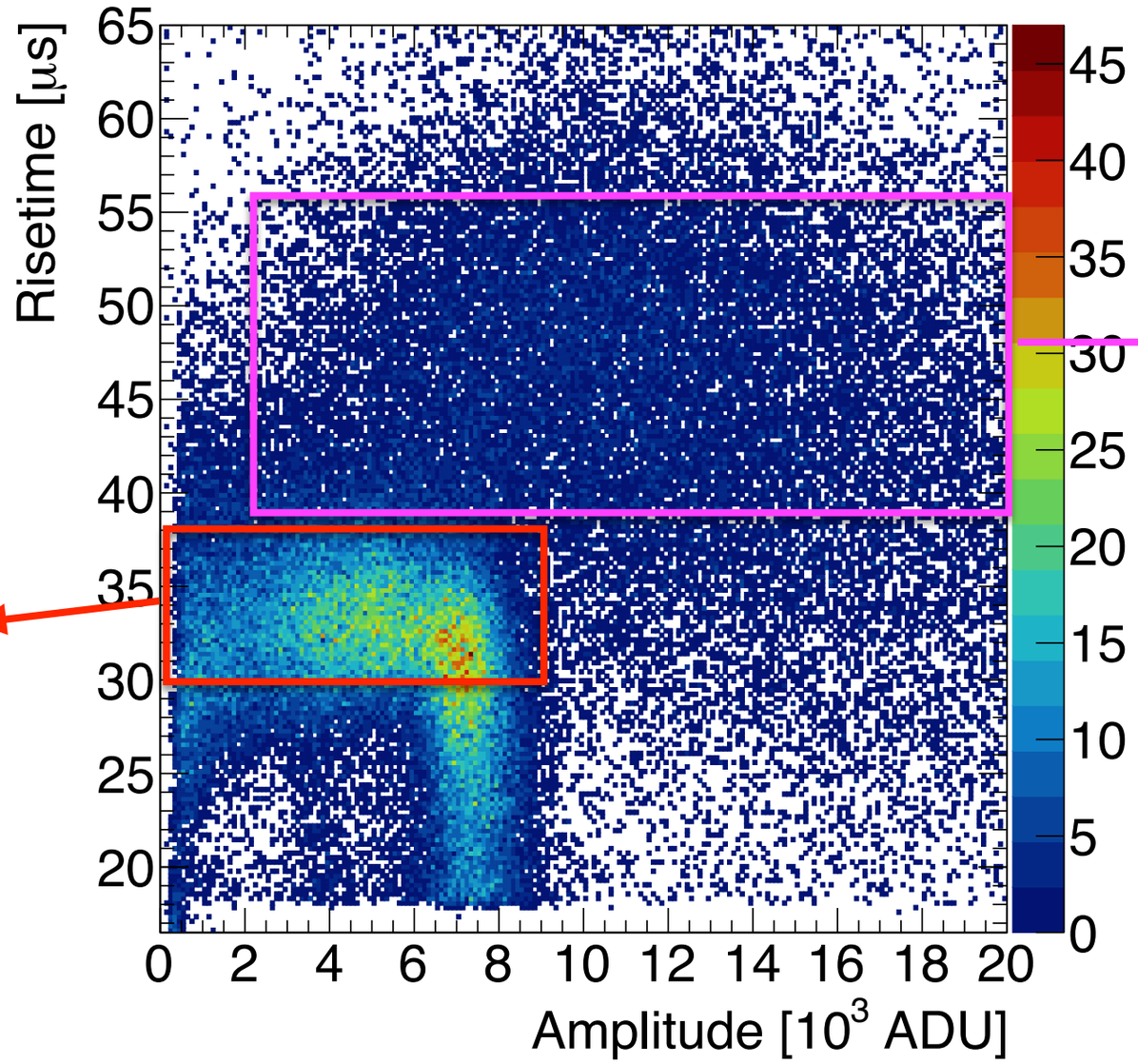


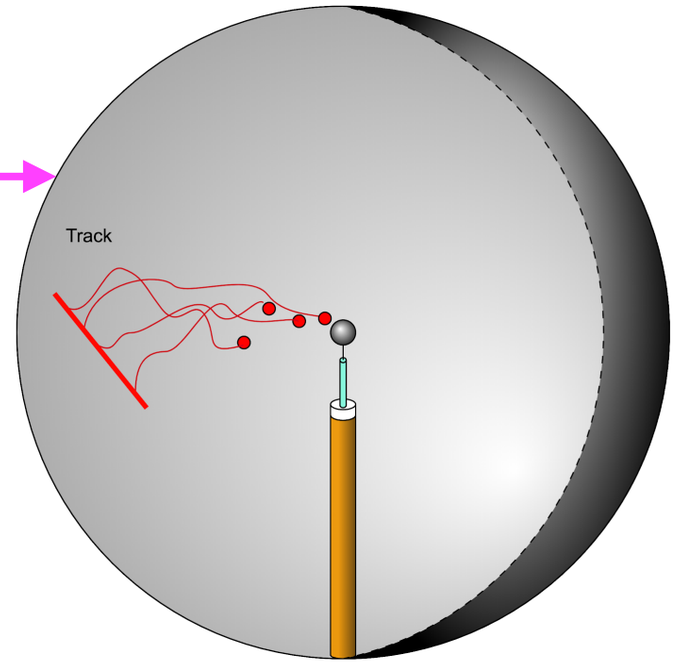
"Muon"-like events

Pulse Shape Discrimination



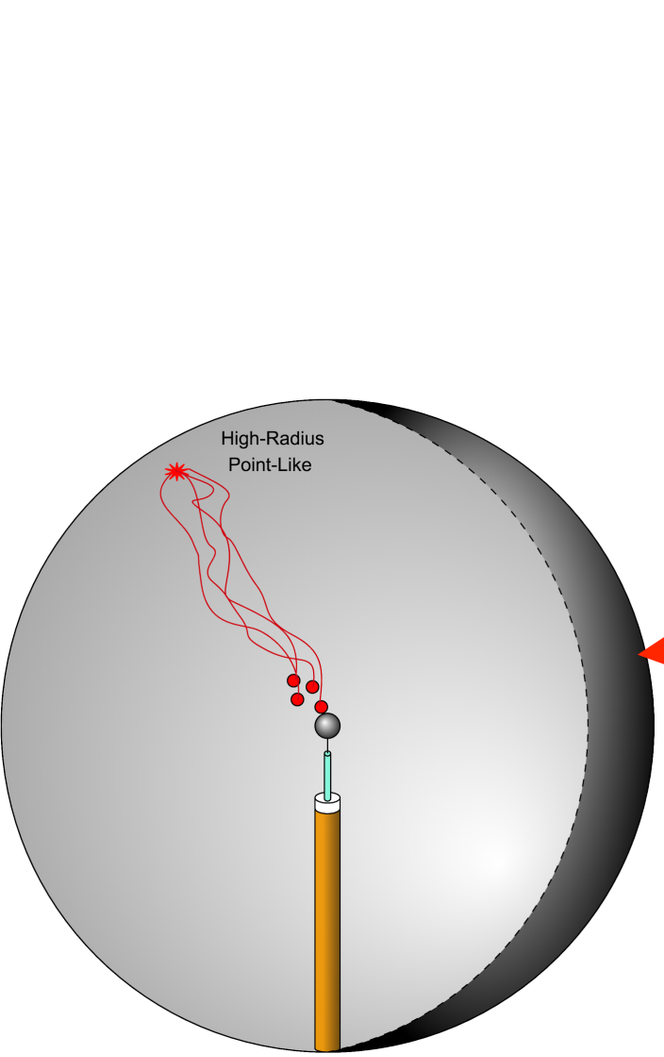
“Surface”-like events



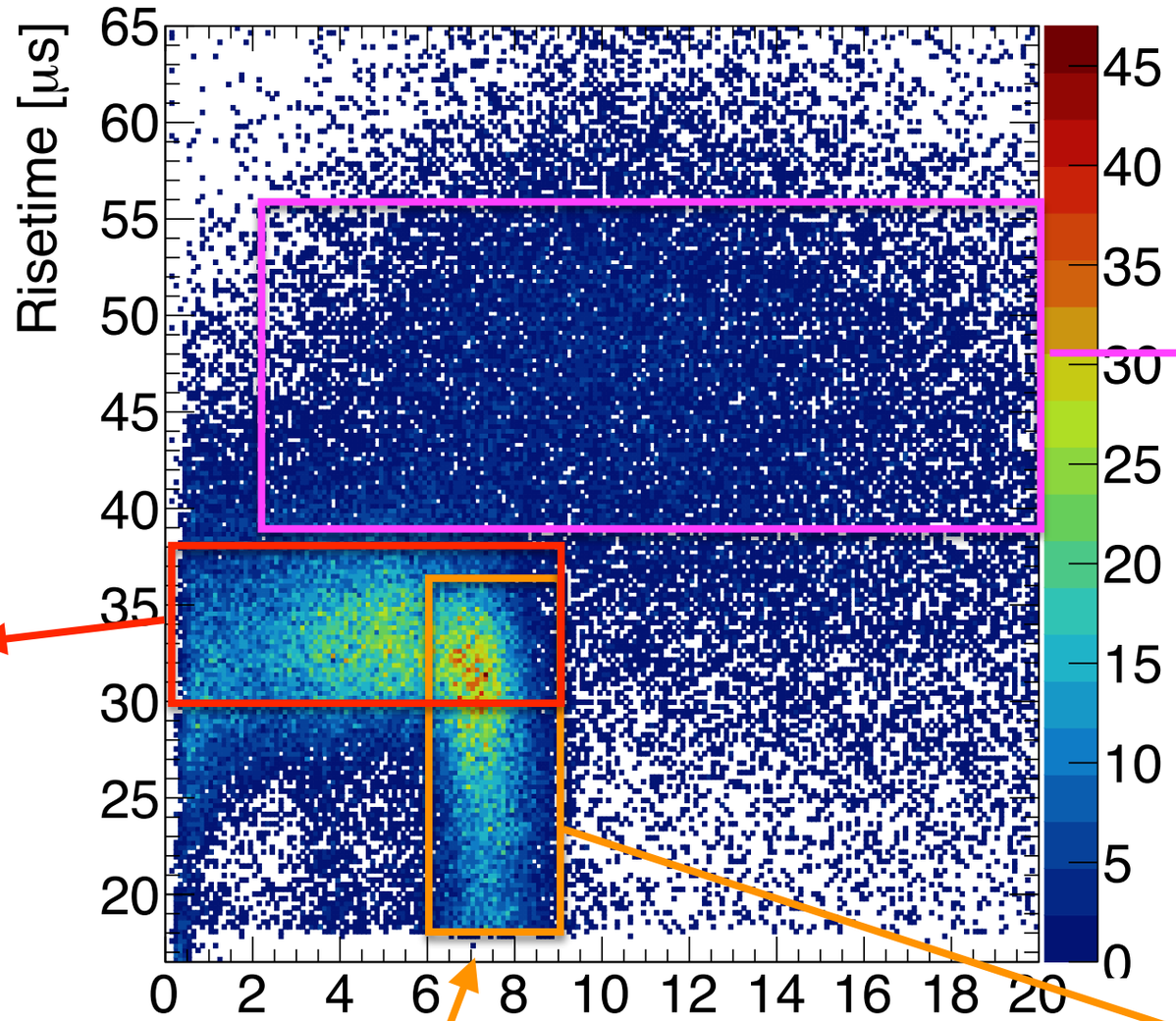


“Muon”-like events

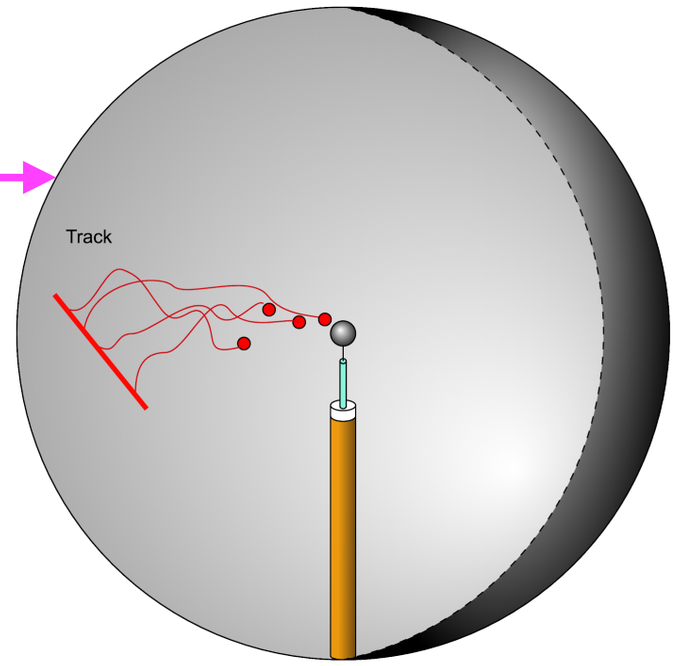
Pulse Shape Discrimination



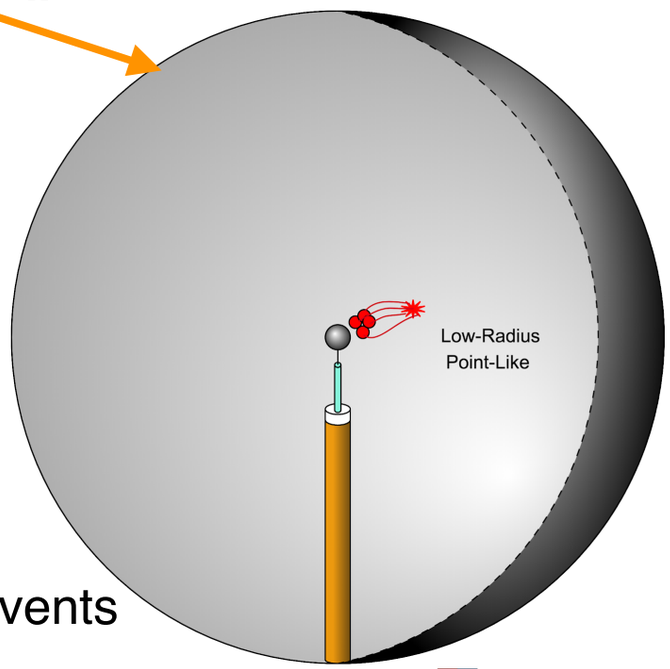
“Surface”-like events



5.9 keV X-rays
from ^{55}Fe decays



“Muon”-like events

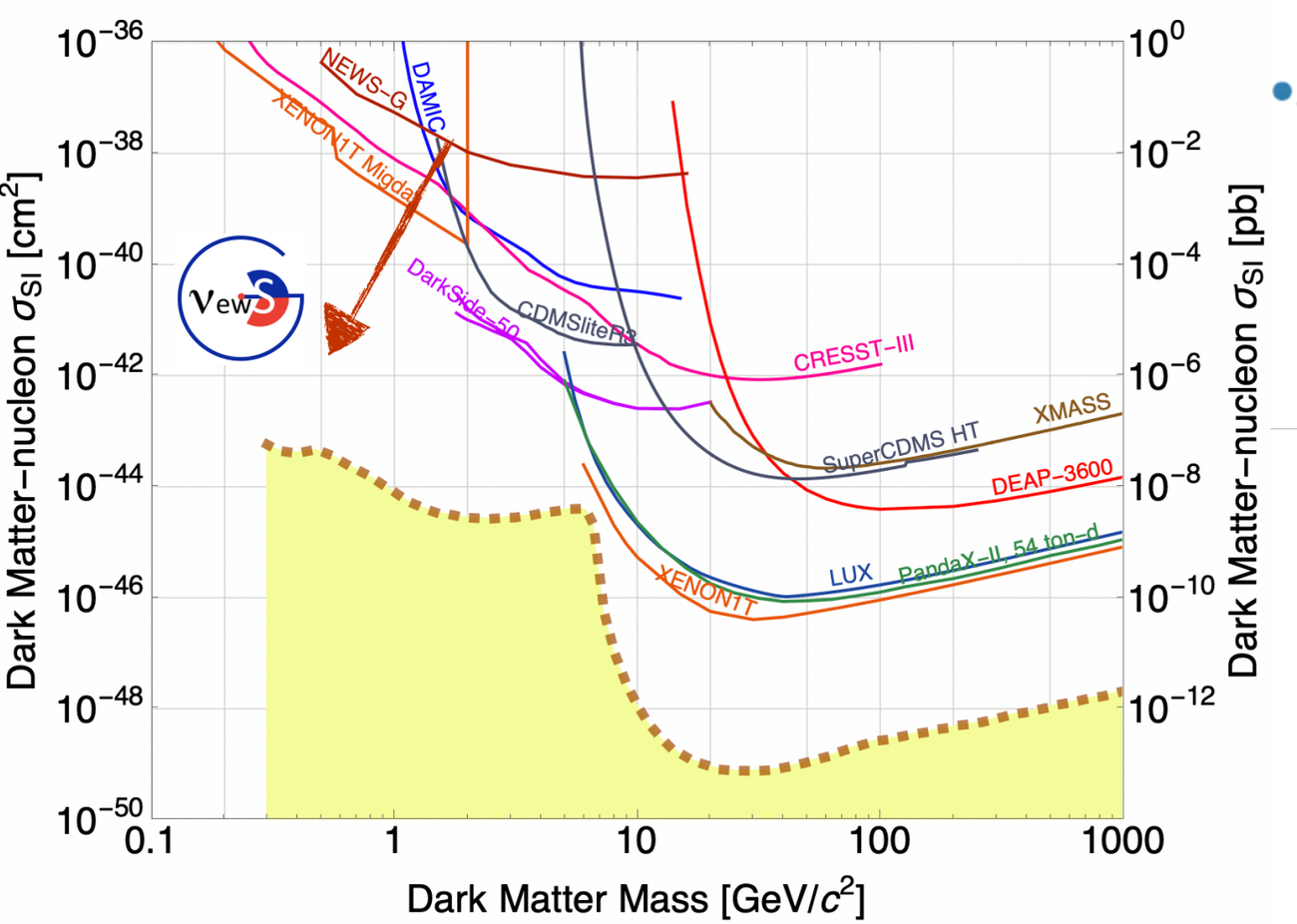


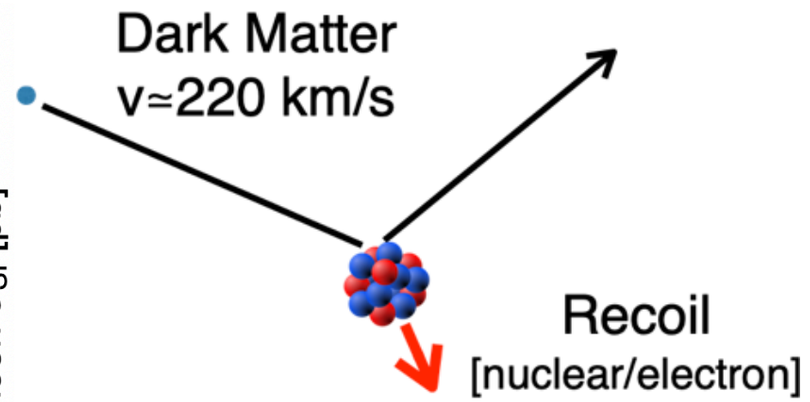
“Signal”-like events

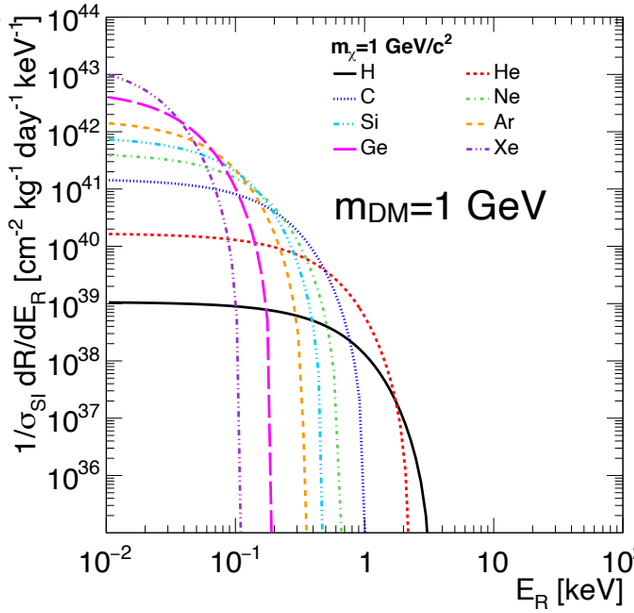
New Experiments With Spheres - Gas

- NEWS-G Collaboration
  - 5 countries
  - 10 institutes
  - ~40 collaborators
- Three underground laboratories
  - SNOLAB
  - Laboratoire Souterrain de Modane
  - Boulby Underground Laboratory

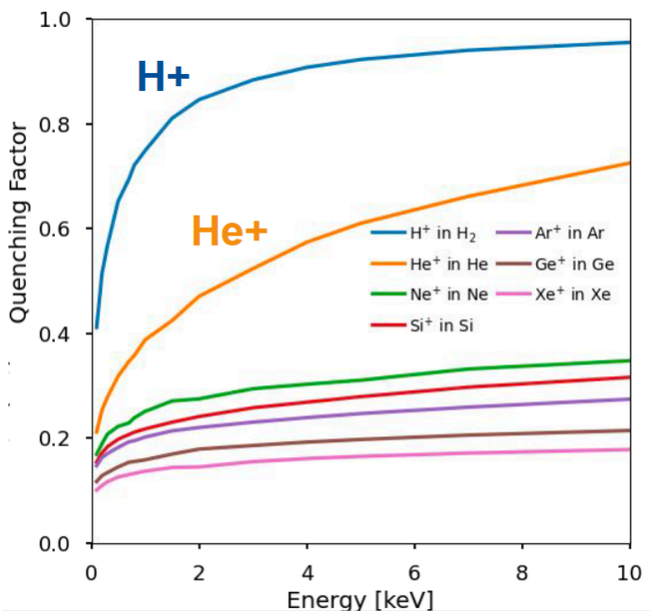
New Experiments With Spheres - Gas





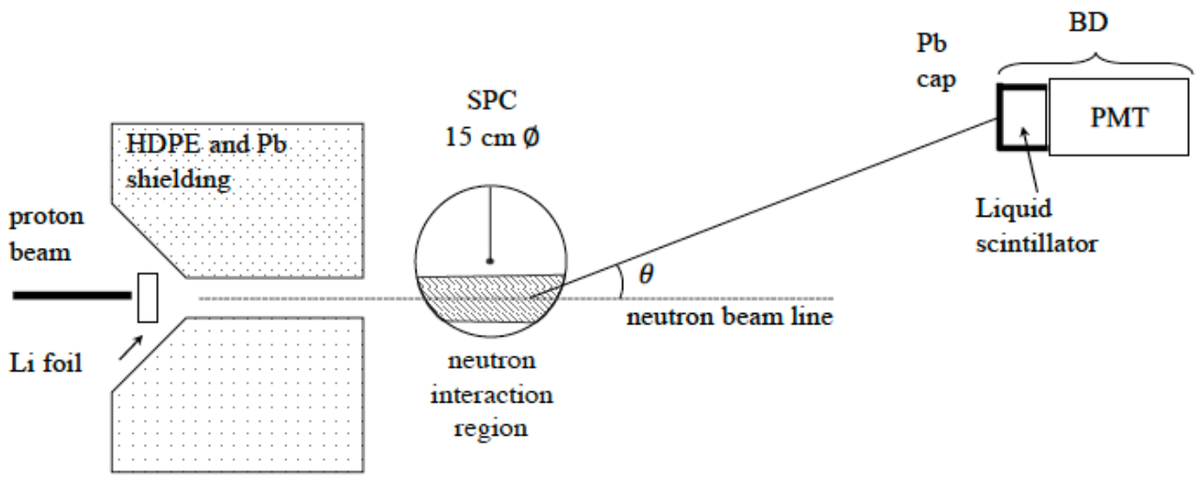


- Search for DM candidates in 0.05 - 10 GeV range
- Direct Detection experiment
  - Novel Spherical Gaseous Proportional Counter
  - Light gases as target (H, He, Ne)
    - Better projectile - target kinematic match
  - Low energy threshold
  - Favourable quenching factor

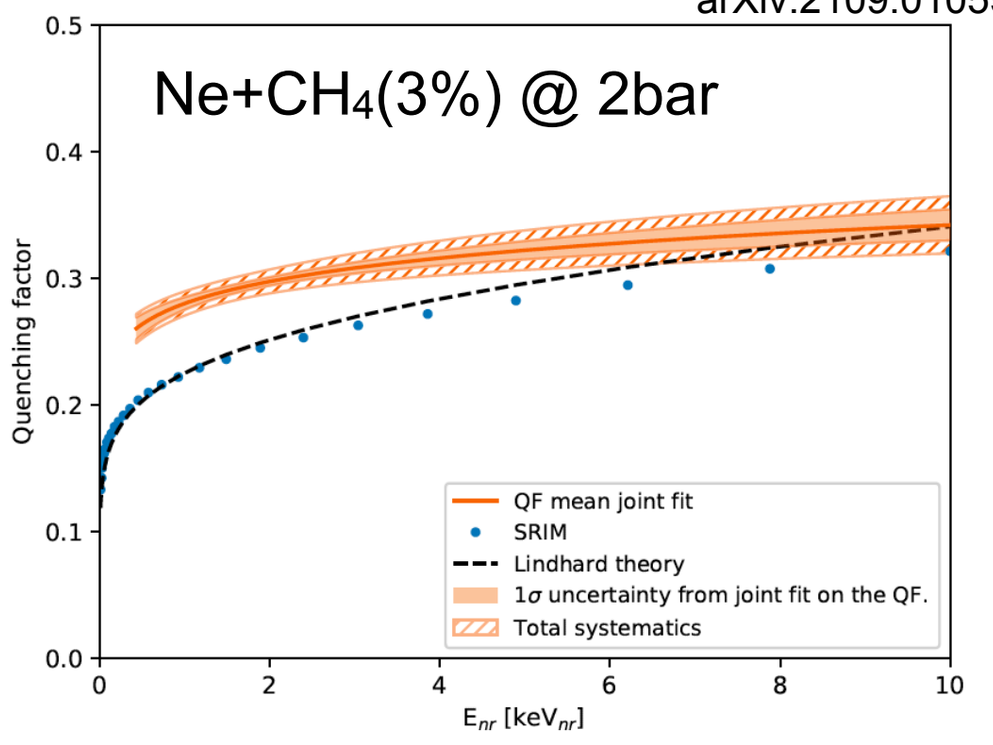


W-value

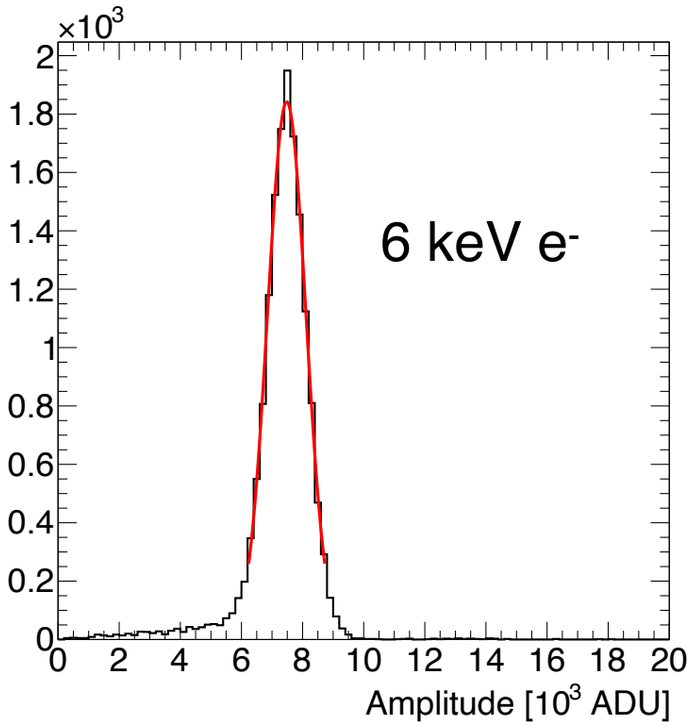
- TANDEM Van de Graaff accelerator at TUNL

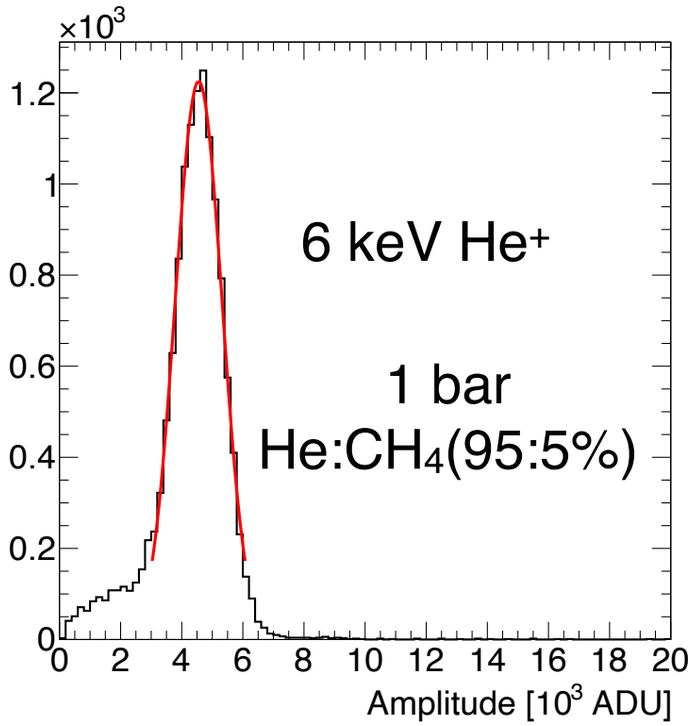


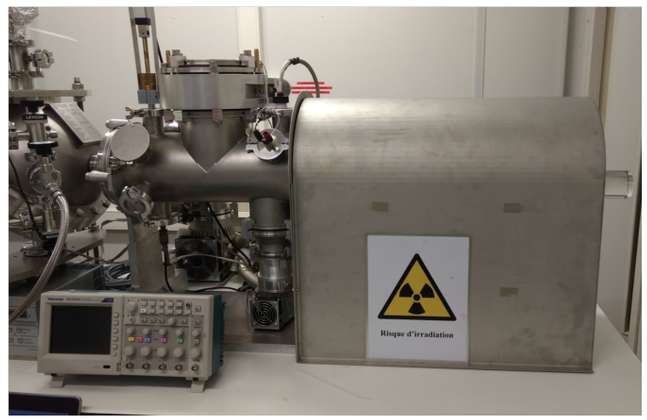
arXiv:2109.01055

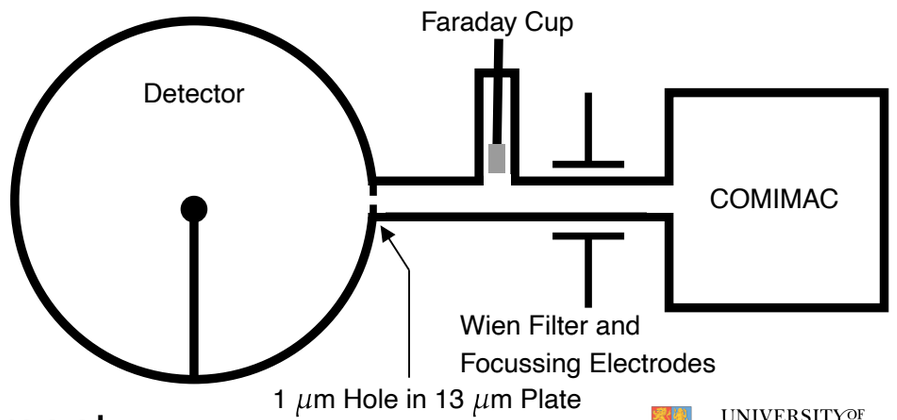


- COMIMAC Facility in Grenoble









W-value

Estimation of the ionisation quenching factor in gases from W-value measurements

arXiv:2105.01414

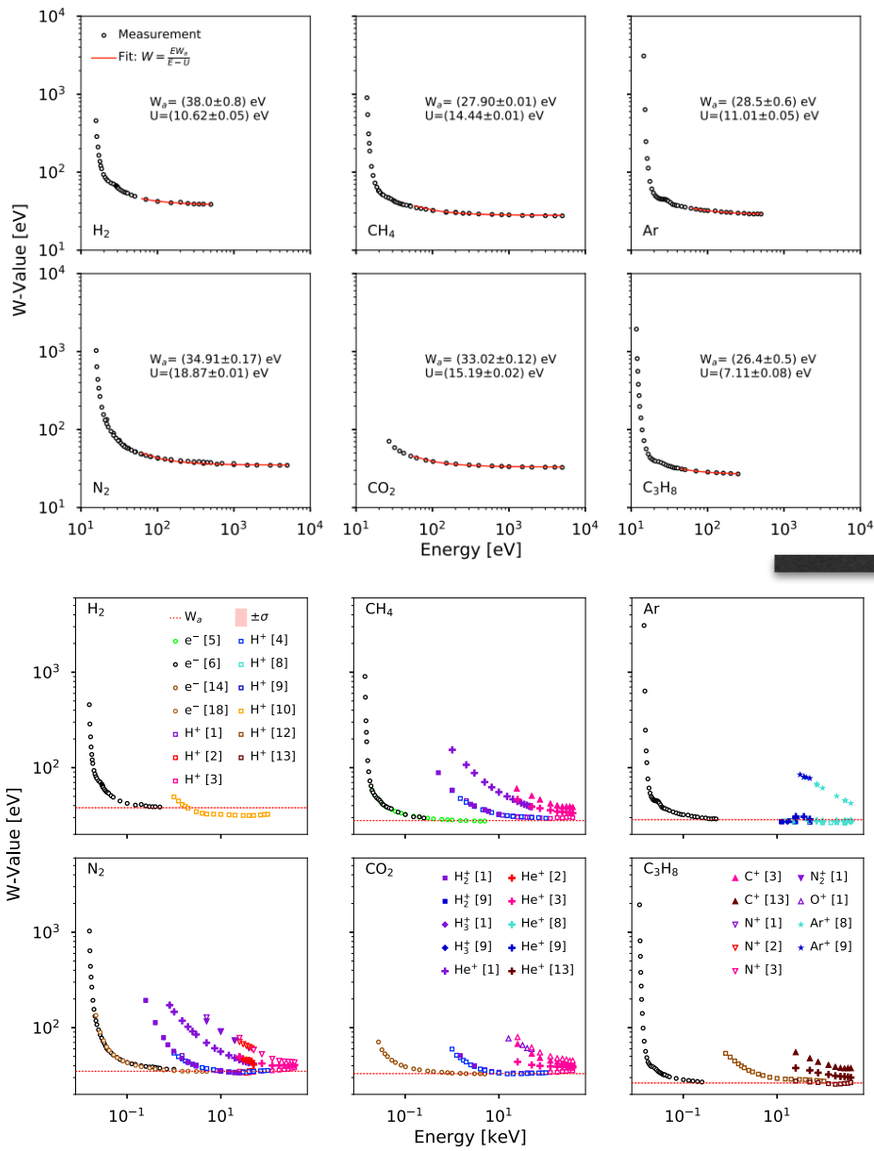
I. Katsioulas,[1,*] P. Knights,[1,2] and K. Nikolopoulos[1]

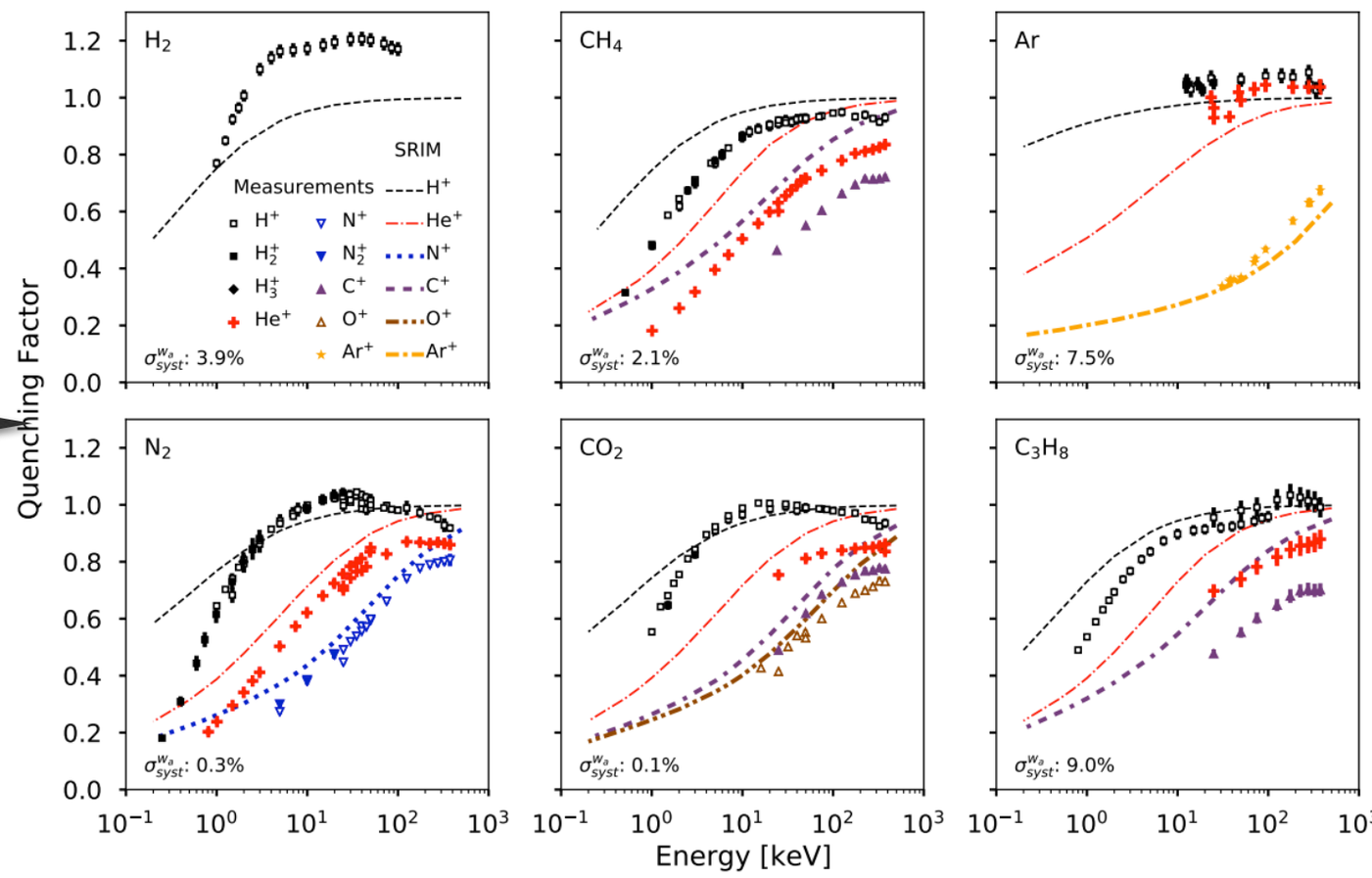
[1]*School of Physics and Astronomy, University of Birmingham, B15 2TT, United Kingdom*
[2]*IRFU, CEA, Universite Paris-Saclay, F-91191 Gif-sur-Yvette, France*

(Dated: May 5, 2021)

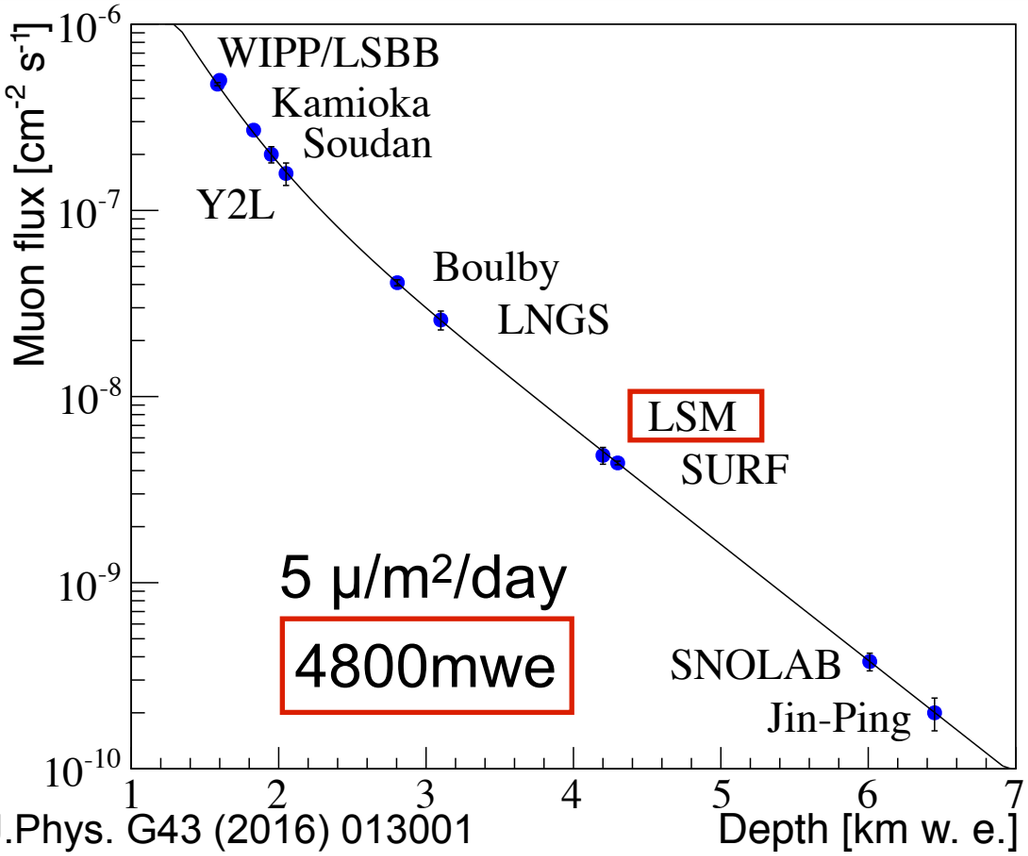
The effect of ionisation quenching for ions is critical for experiments relying on the measurement of low energy recoils, such as direct Dark Matter searches. We present ionisation quenching factor estimates over a range of energies for protons, α-particles, and heavier ions in H_2, CH_4, N_2, Ar, CO_2, and C_3H_8 gases, estimated from the respective reference W-value measurements. The resulting ionisation quenching factors are compared with predictions from SRIM.

$$q_f = \frac{E_e e}{E} = \frac{N_i^i \cdot W_e(E)}{E} = \frac{W_e(E)}{W_i(E)}$$

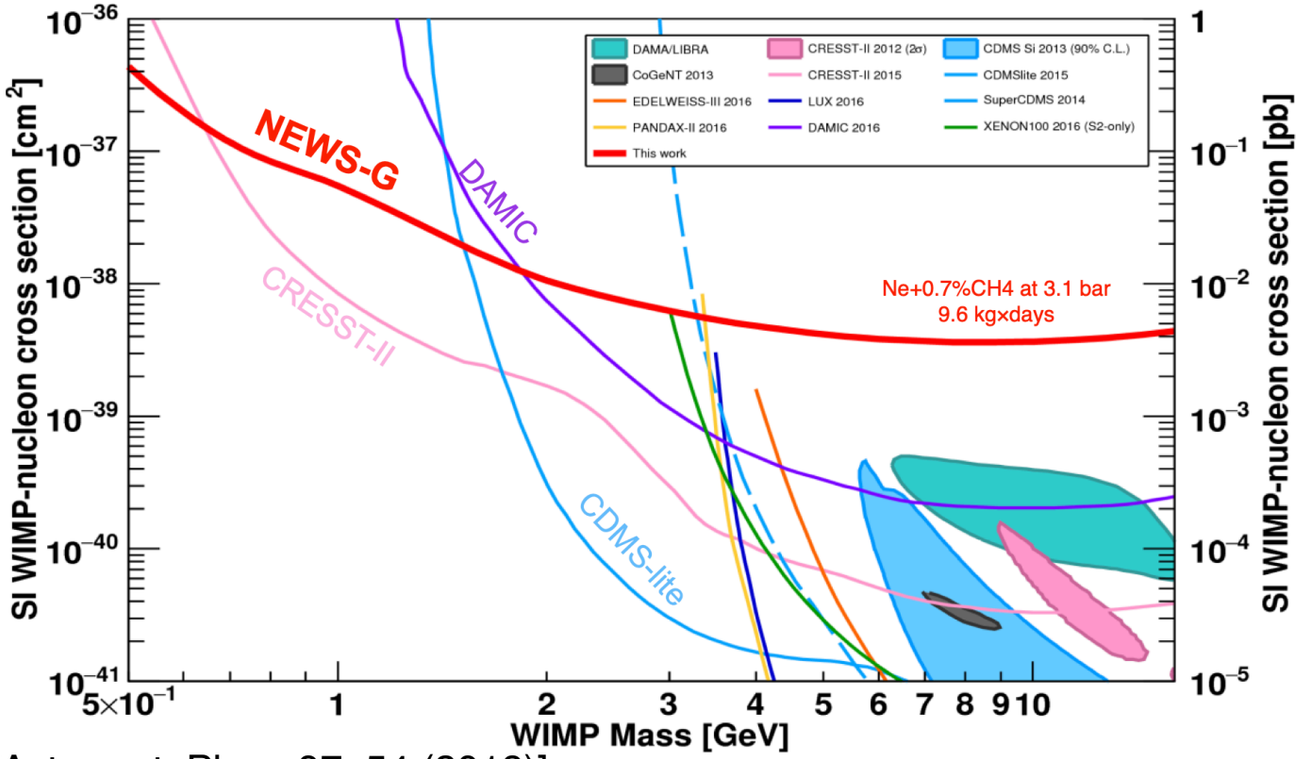




NEWS-G: Prototype at LSM

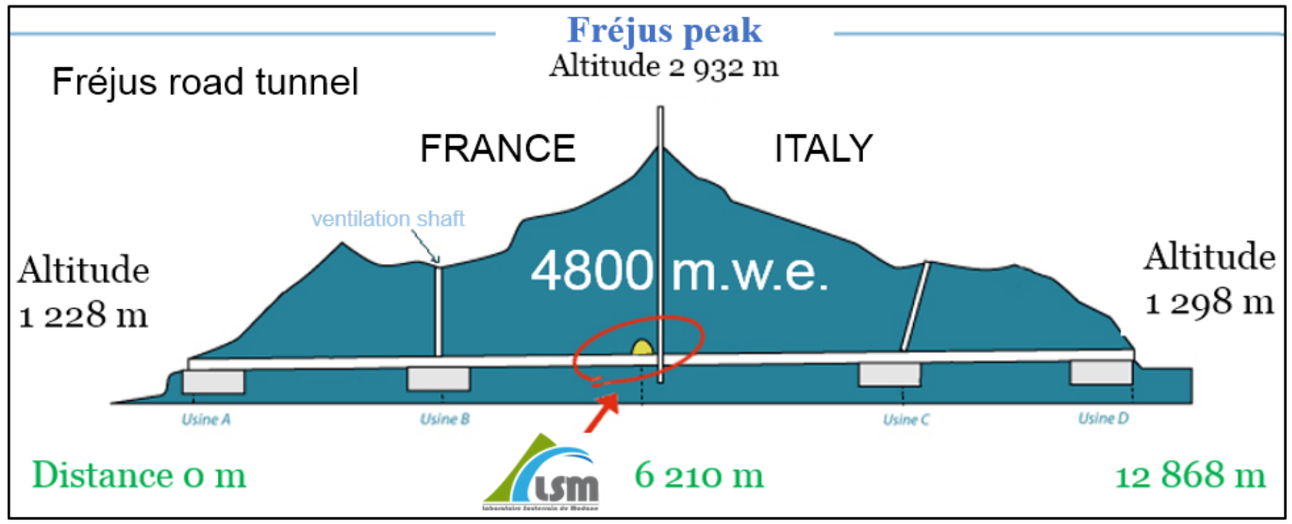


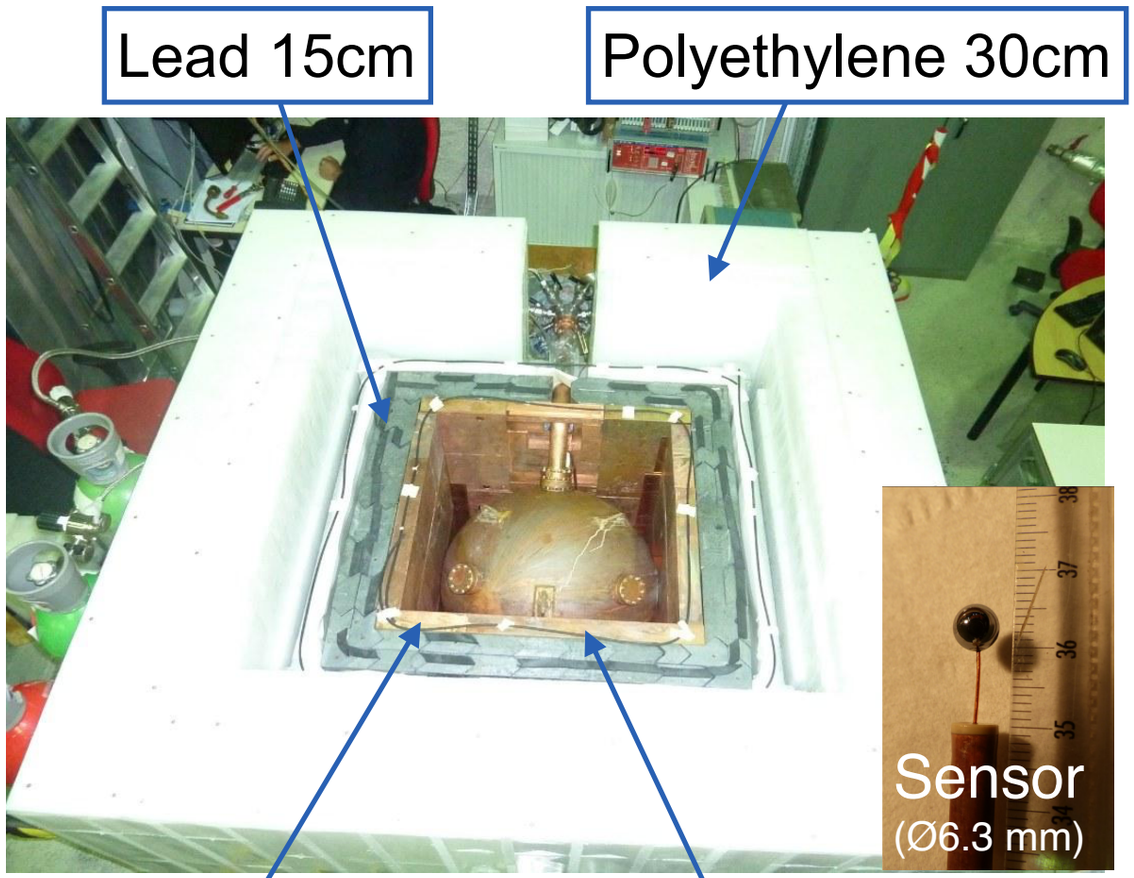
J.Phys. G43 (2016) 013001



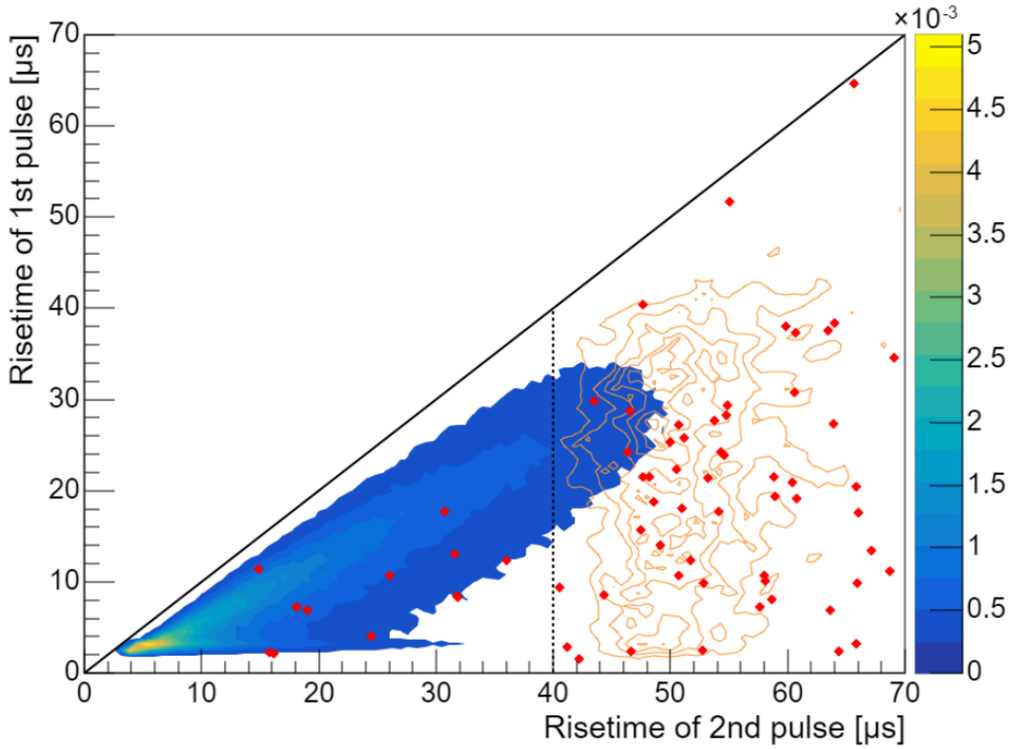
[Astropart. Phys. 97, 54 (2018)]

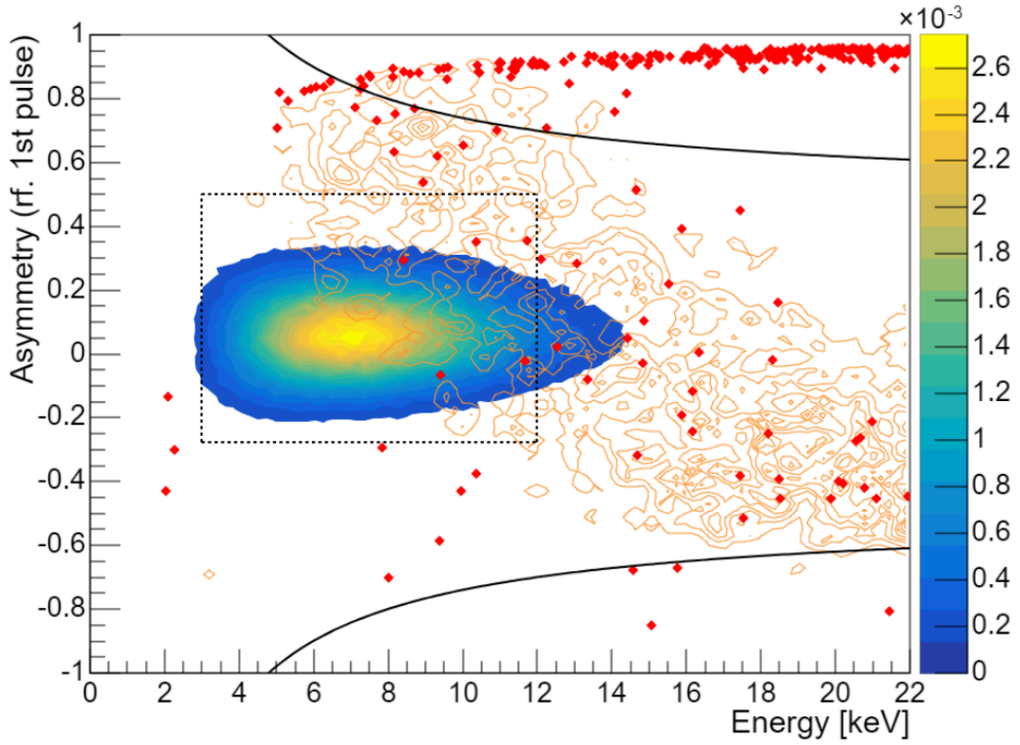
Laboratoire Souterrain de Modane

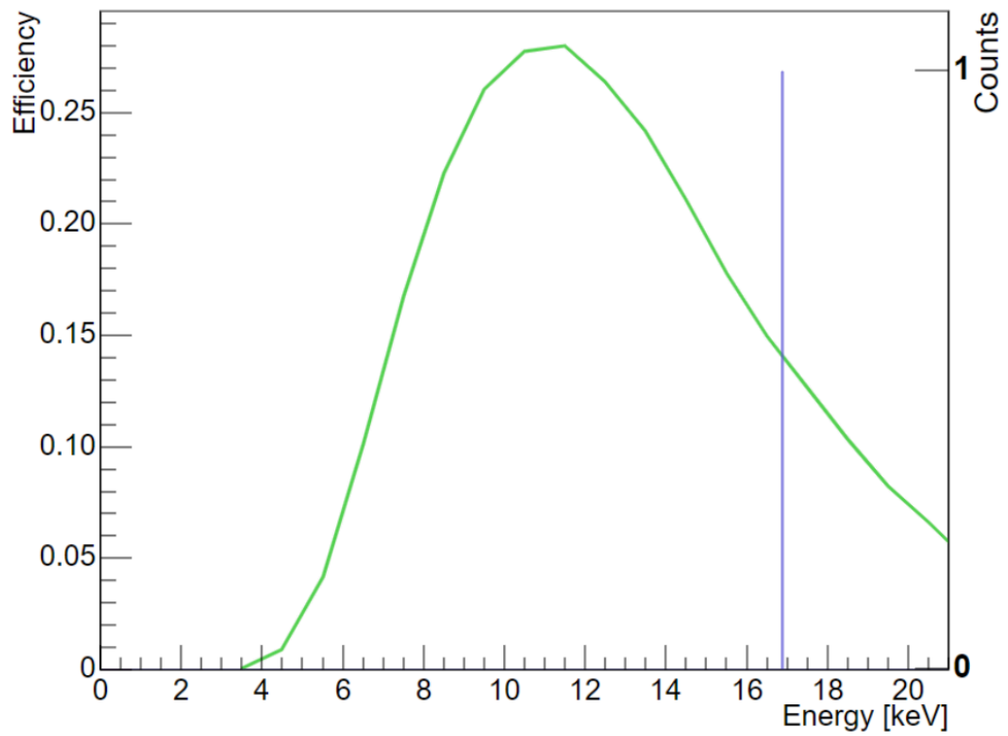


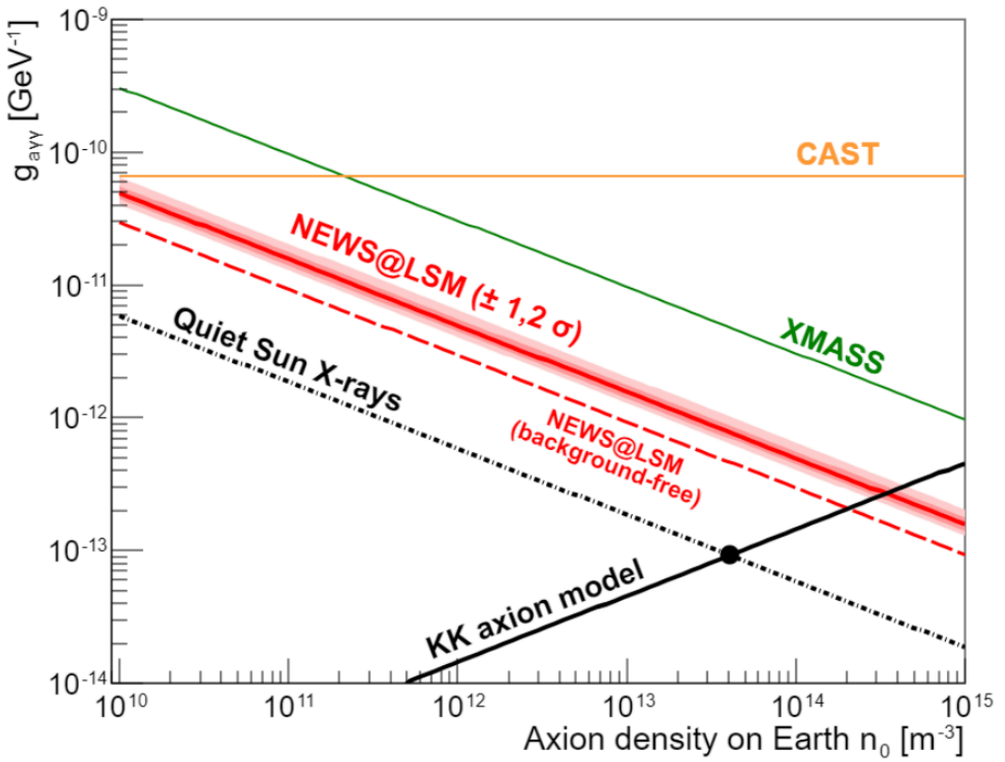


Search for Solar Kaluza-Klein axions









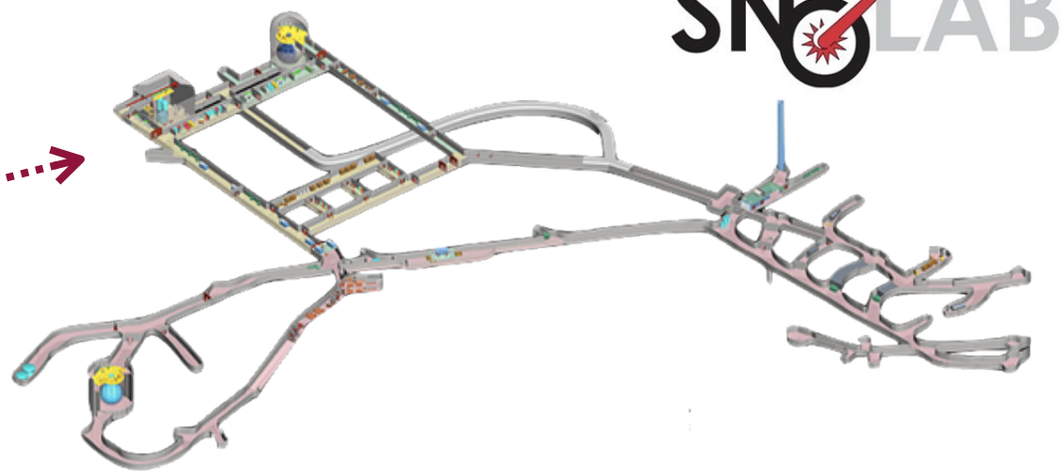
arXiv:2109.03562

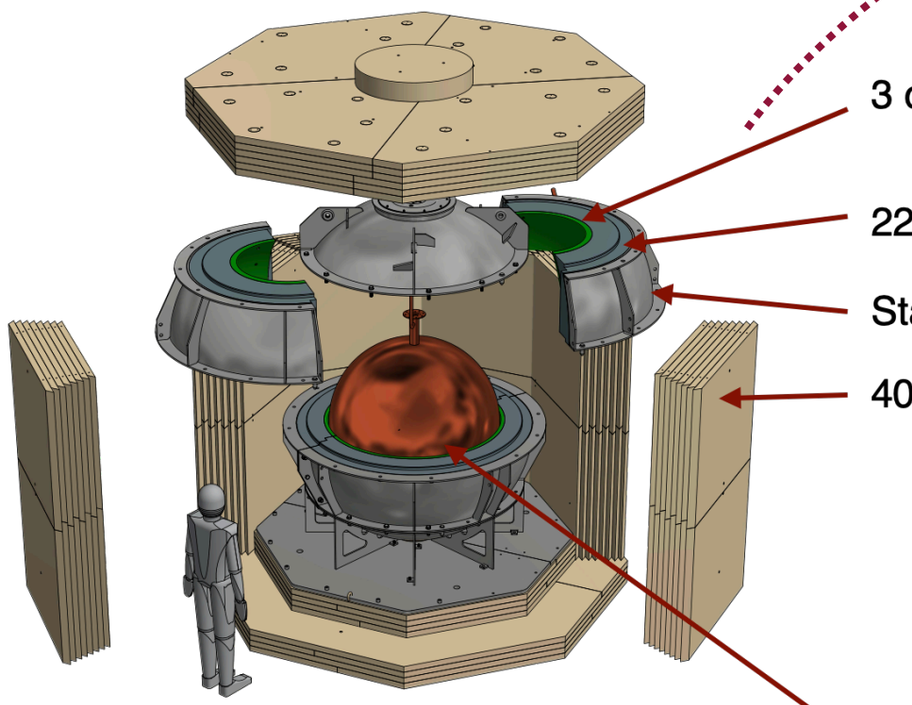
NEWS-G at SNOLAB

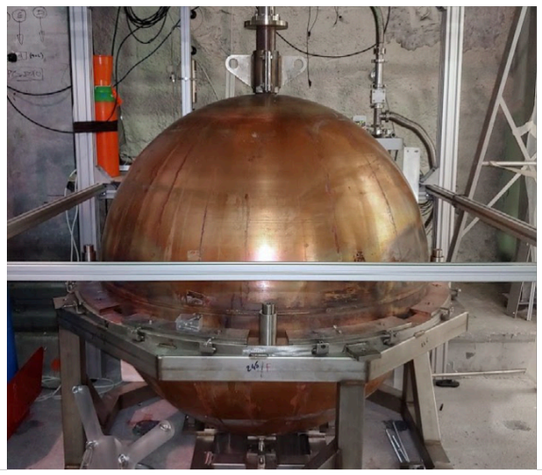
- First NEWS-G results obtained with SEDINE
  - ⌀60 cm detector installed at Modane

[Astropart. Phys. 97, 54 (2018)]

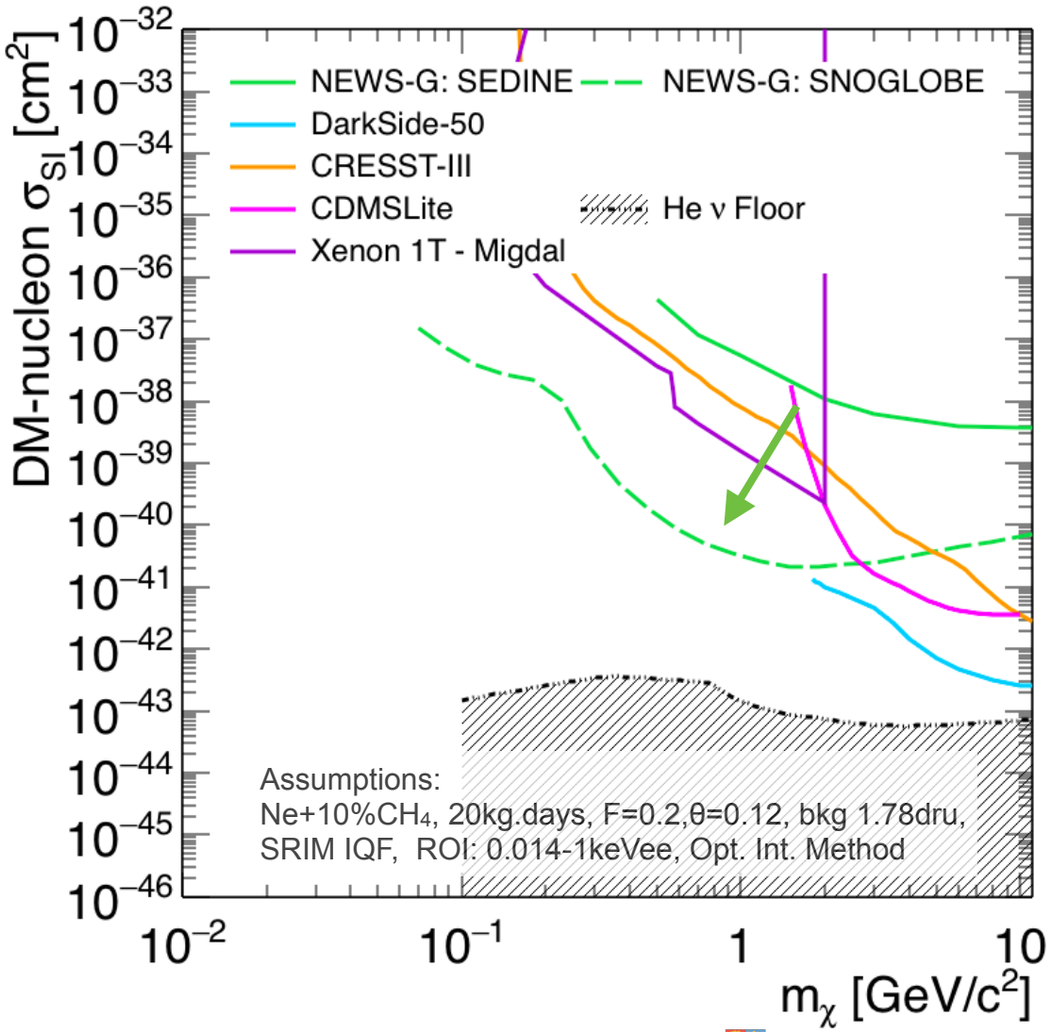
- ⌀140 cm detector installed at SNOLAB
  - Detector commissioning on-going
  - Physics data-taking to follow





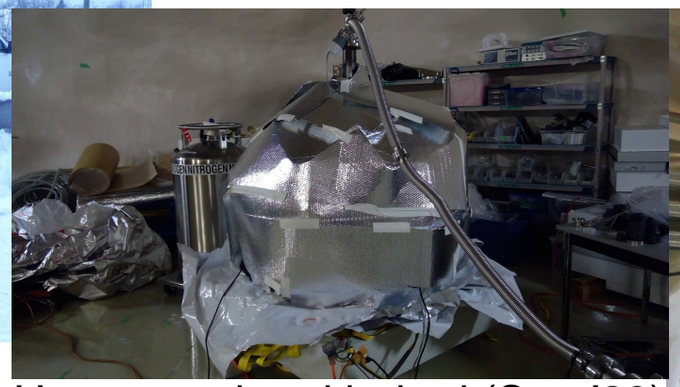


Ø140 cm
4N Copper (99.99% pure)
Assembled at LSM

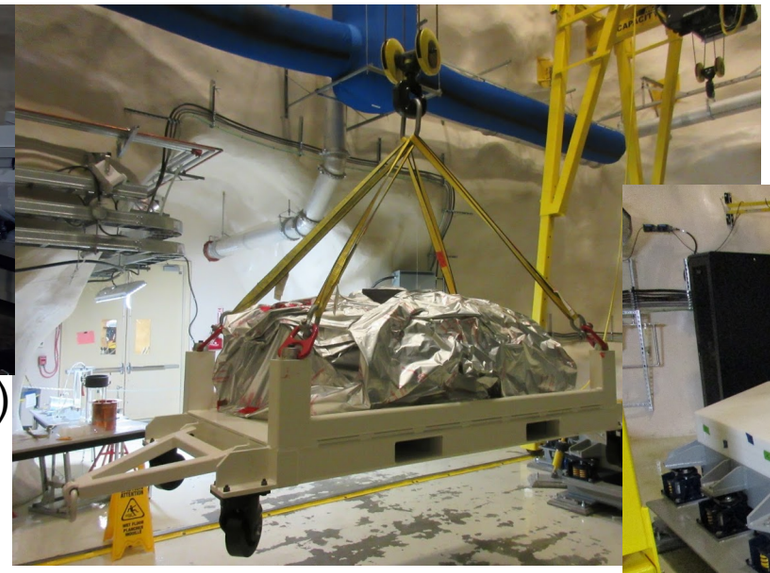


Installation at SNOLAB

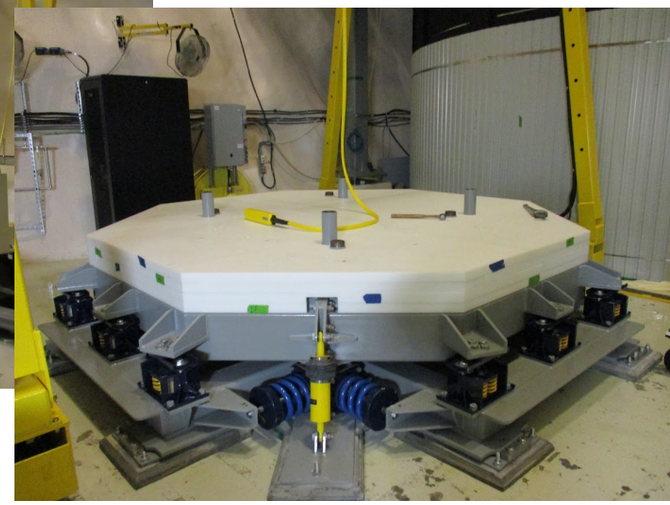
Arrival at SNOLab (Dec ’19)



Unwrapped and baked (Sep ’20)

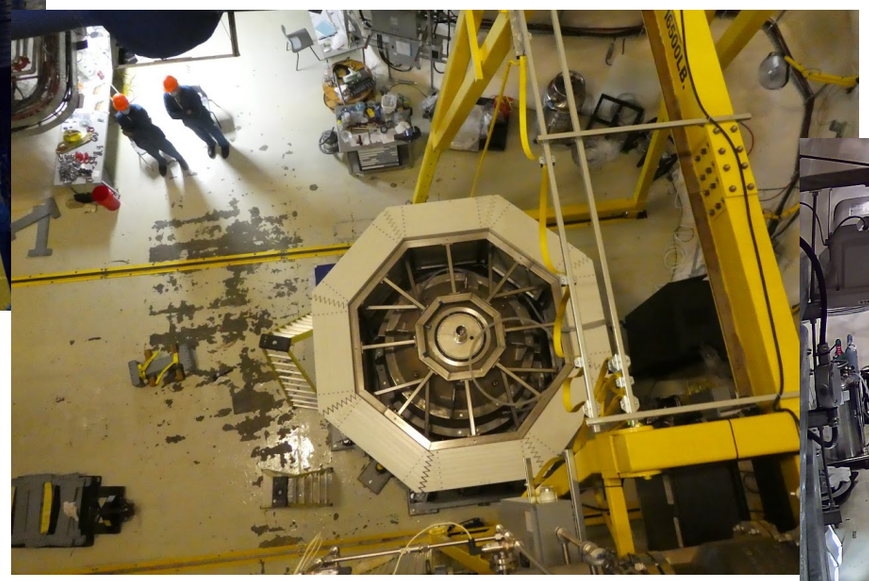


Pb shielding arrival



Seismic platform installation

Detector Installation

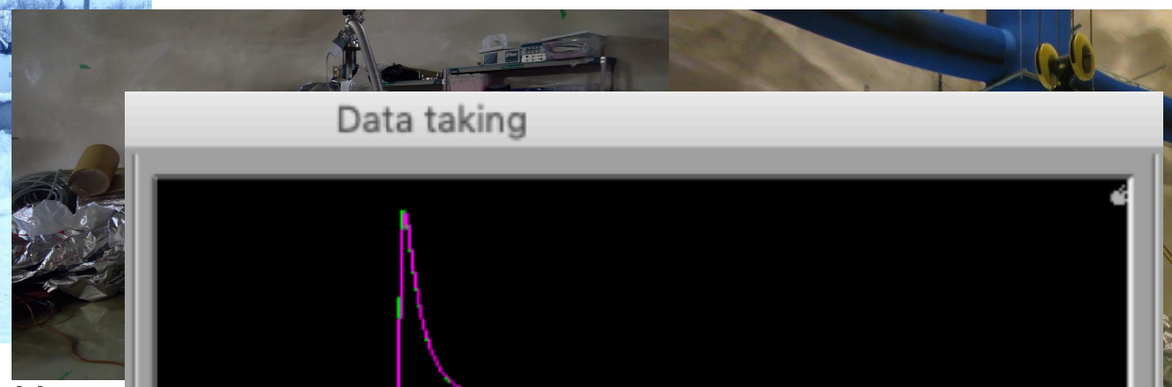


PE shielding installation

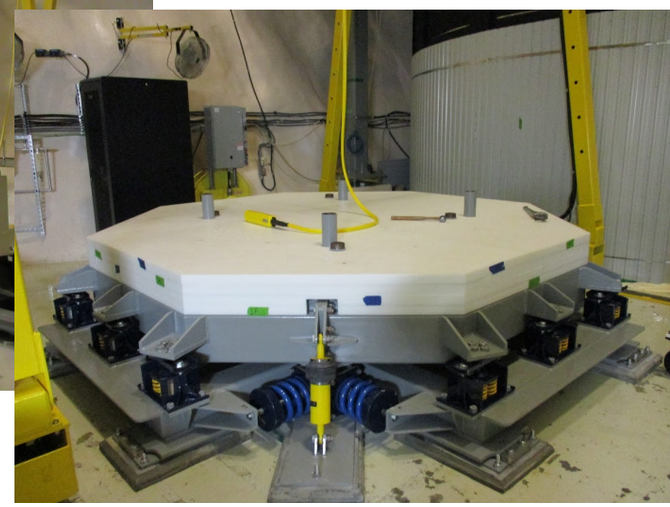
SNOGLOBE complete (Dec ’20)

Installation at SNOLAB

Arrival at SNOLab (Dec ’19)

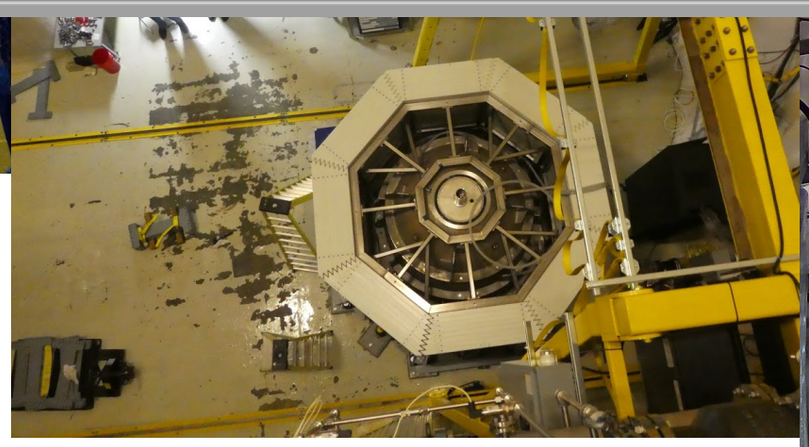


Unwra



Seismic platform installation

Detector Installation



PE shielding installation

SNOGLOBE complete (Dec ’20)

Reducing Backgrounds

Copper Electroplating

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

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

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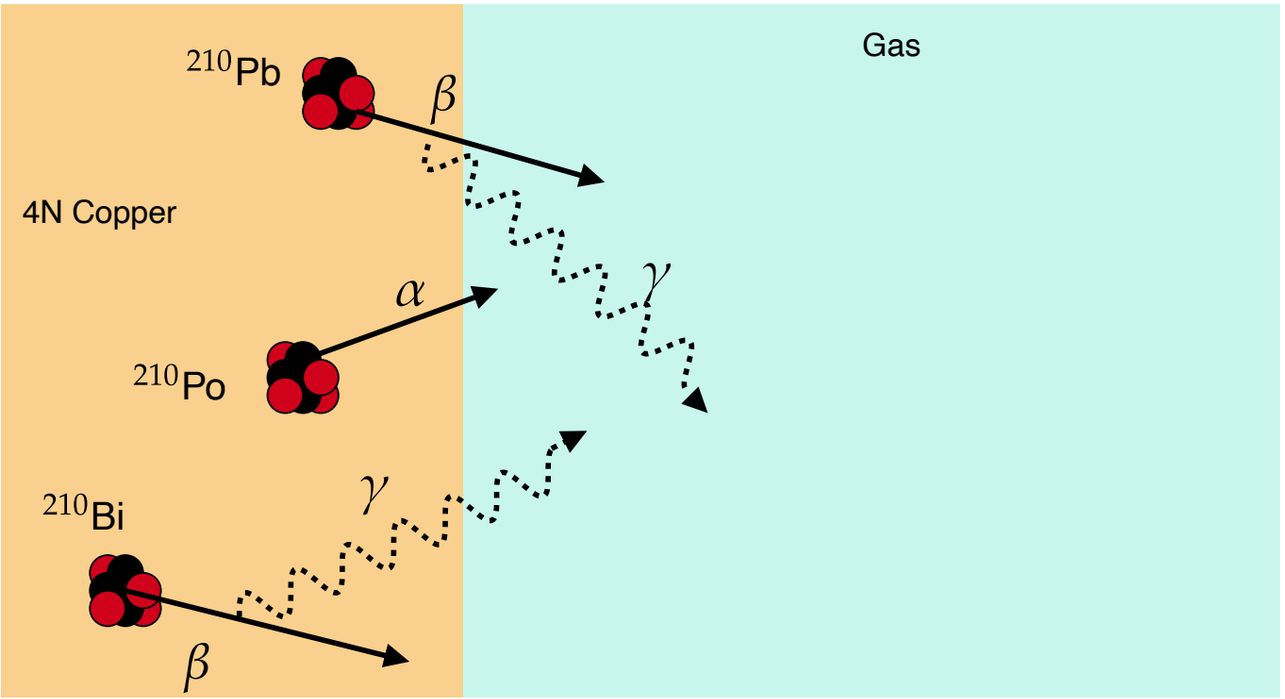
- Bremsstrahlung X-rays from ^{210}Pb and ^{210}Bi β-decays in Cu



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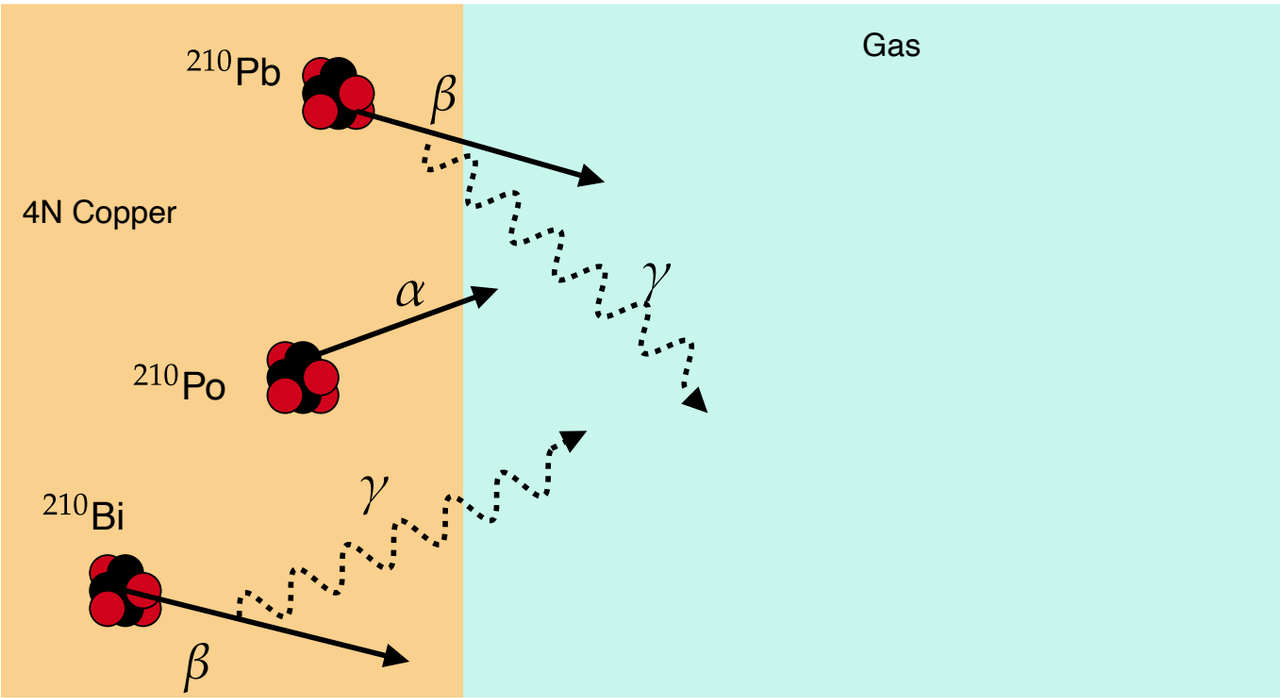
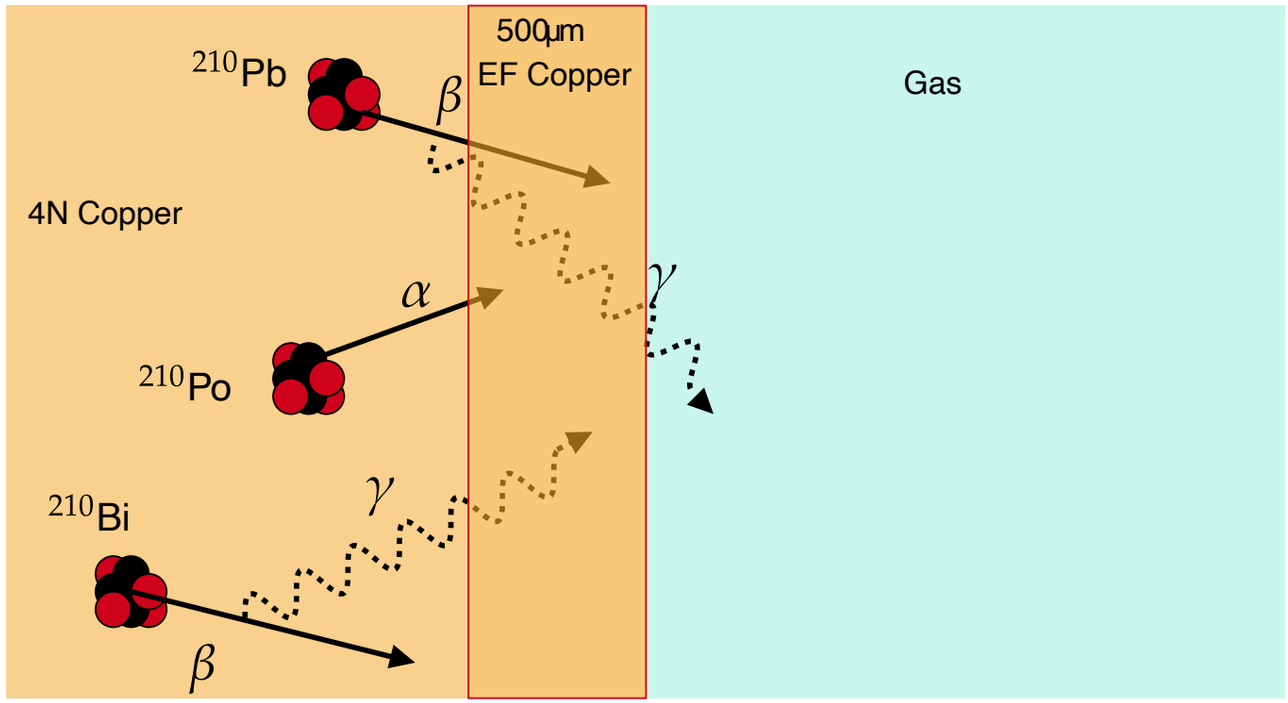
Internal shield

- Ultra-pure Cu layer on detector inner surface
- Suppresses ^{210}Pb and ^{210}Bi backgrounds by factor 2.6 under 1 keV





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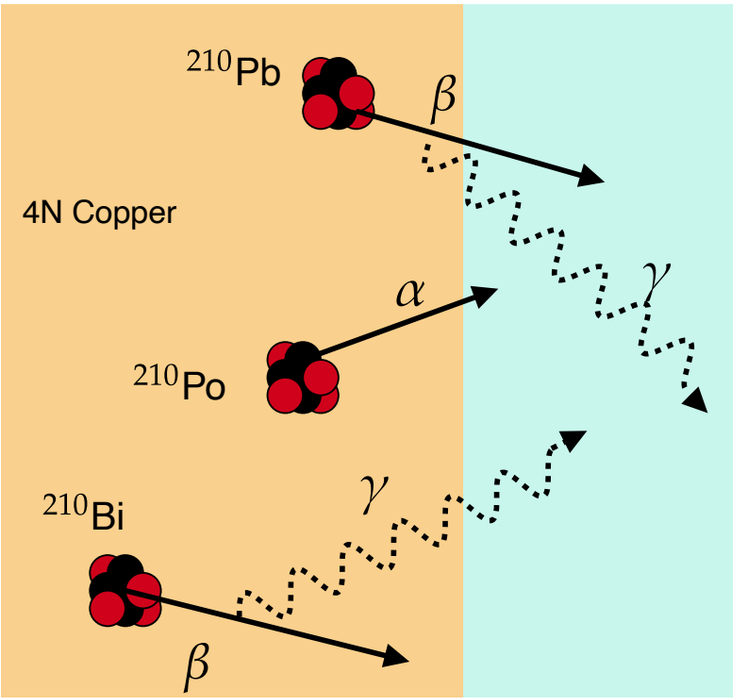

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Copper electroplating for background suppression in the NEWS-G experiment

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)

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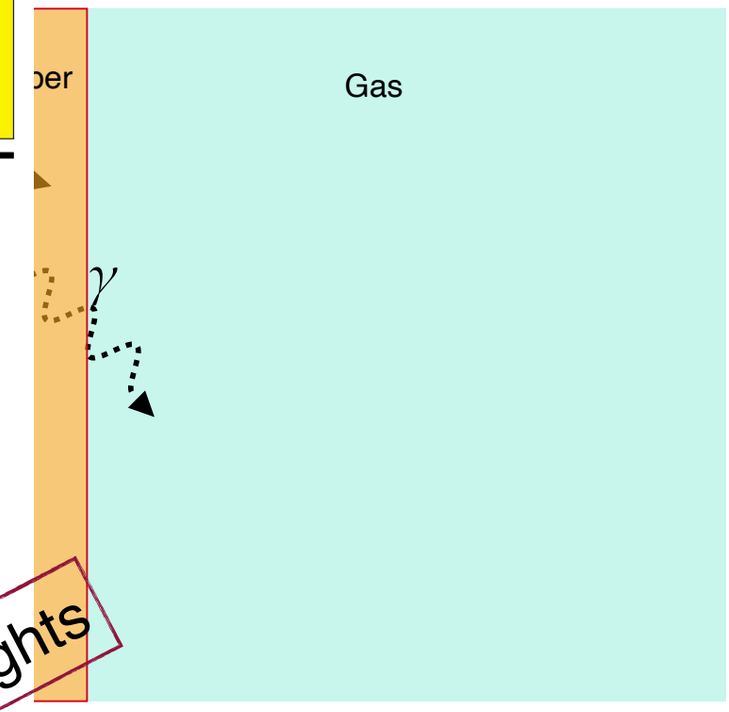
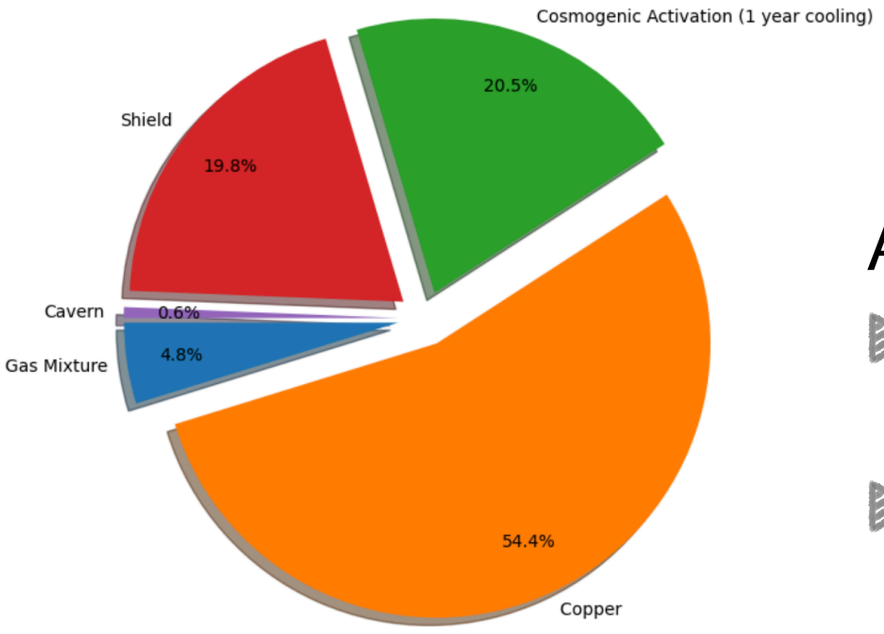
Talk by P. Knights



Electroformed Cuprum Manufacturing Experiment

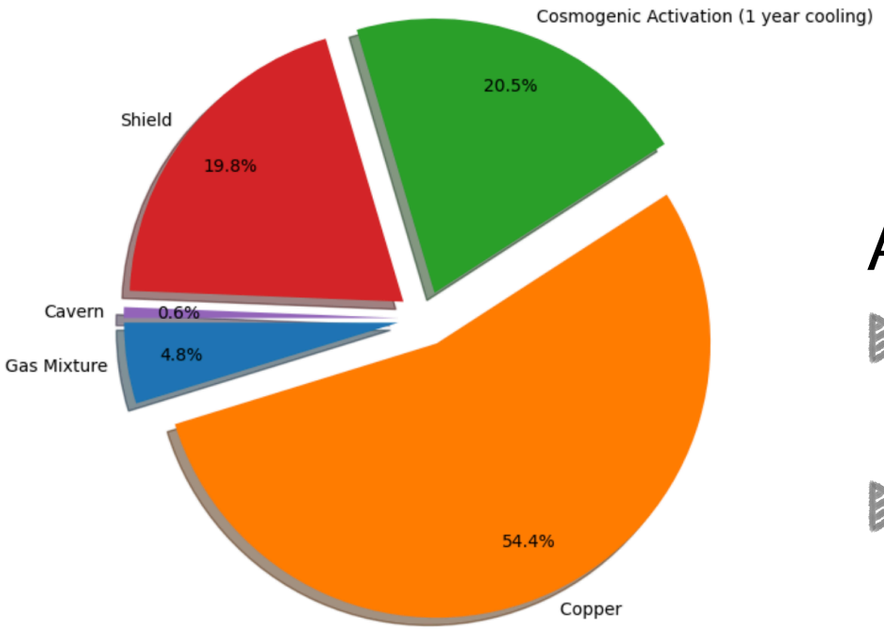


ECuME

A ⌀140 cm sphere electroformed underground in SNOLAB

- Builds on achievements of NEWS-G electroplating
  - 36 μm/day → ~1 mm/month
- No machining or welding - grow sphere directly

Electroformed Cuprum Manufacturing Experiment



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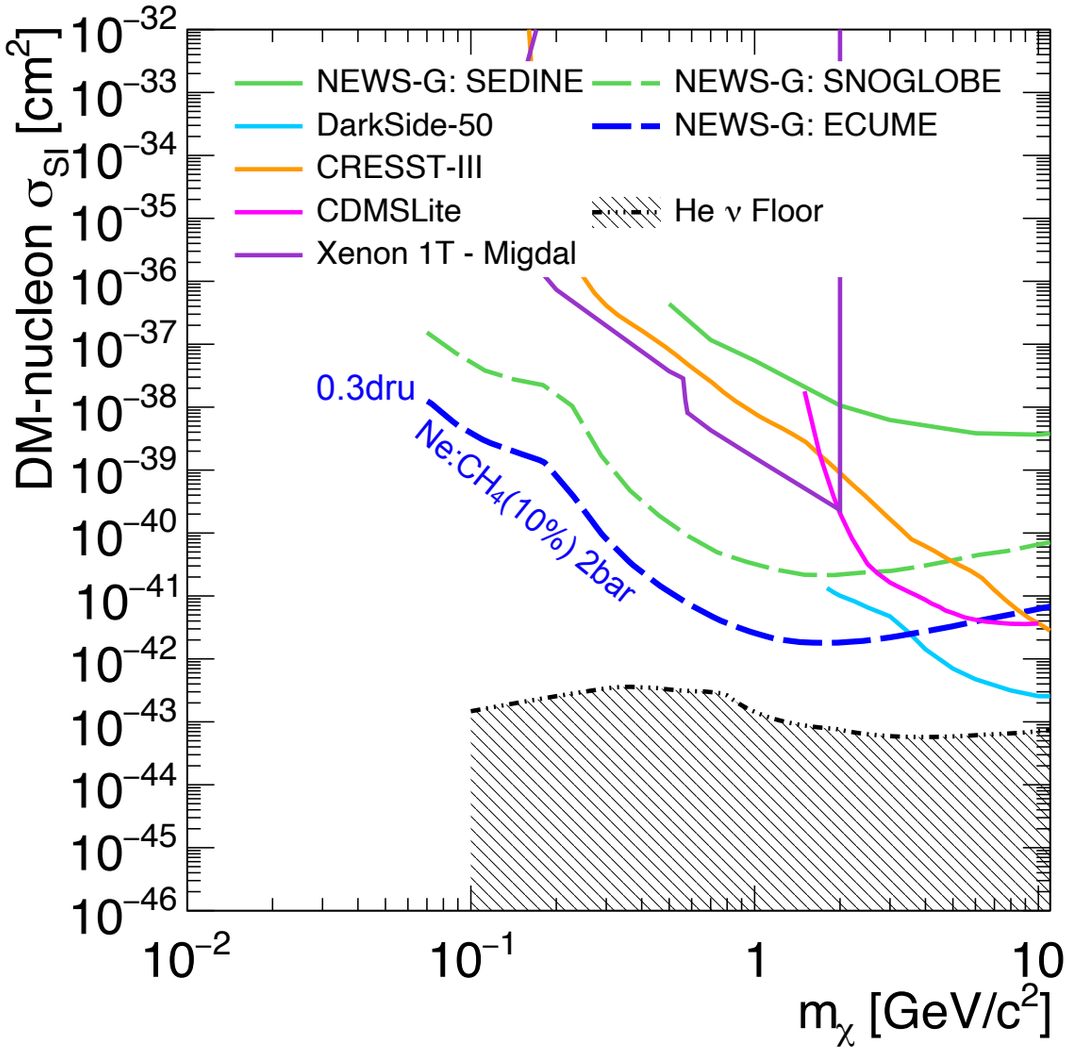

Current Status

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

Increasing Target Mass

Increasing Target Mass

Single anode: Drift and Amplification fields are connected $E = \frac{V_a}{r^2}\frac{r_a r_c}{r_c - r_a} \approx \frac{V_a r_a}{r^2}$

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- ACHINOS: Multi-anode sensor JINST 12 (2017) 12, P12031
  - Multiple anodes placed at equal radii
  - Decoupling drift and amplification fields
  - Opportunity: individual anode read-out

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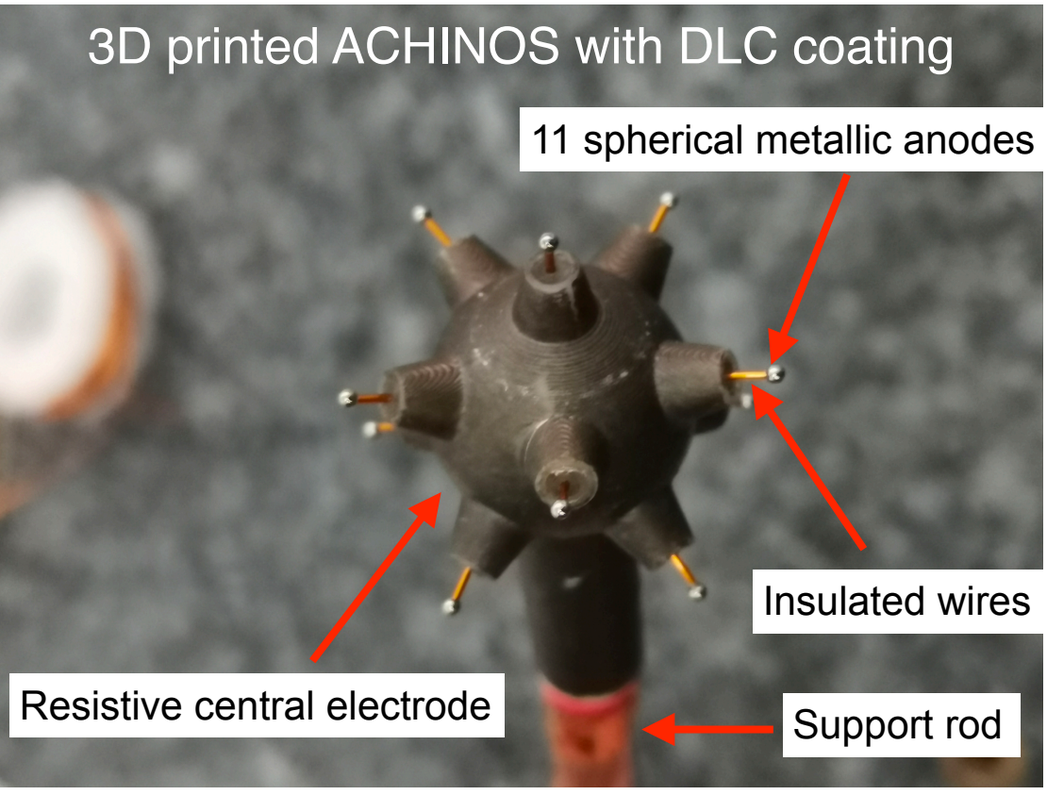

JINST 15 (2020) 11, 11

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Αχινός (greek. sea urchin)

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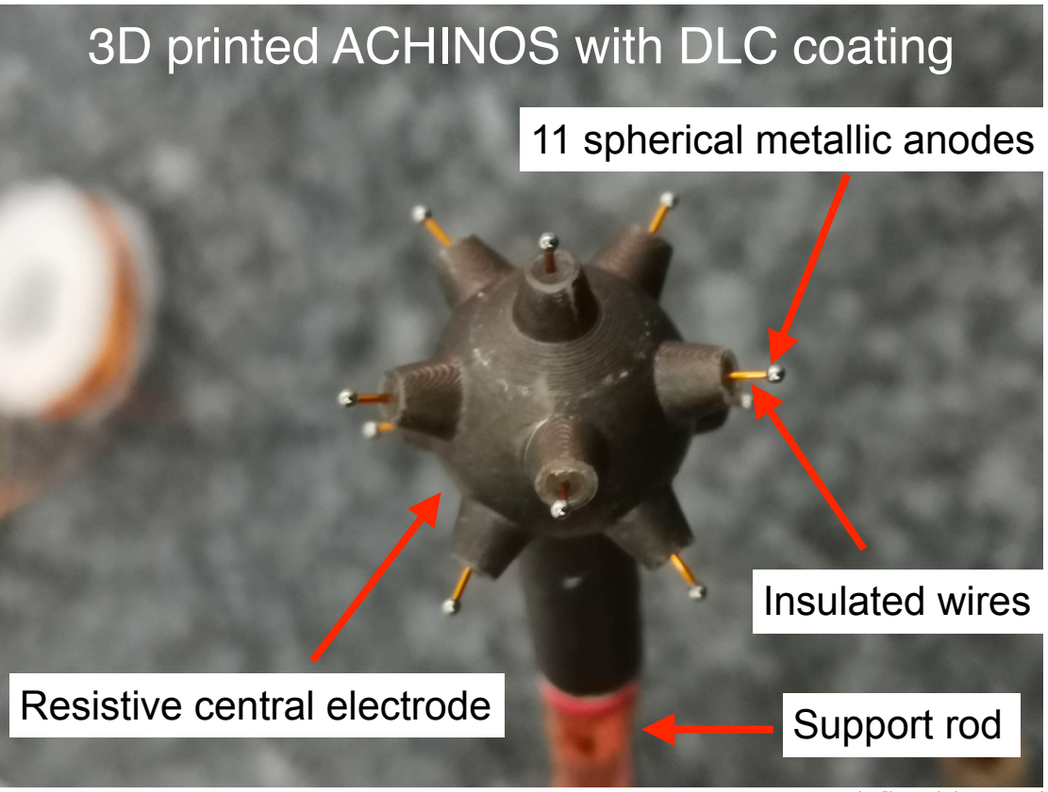

JINST 15 (2020) 11, 11

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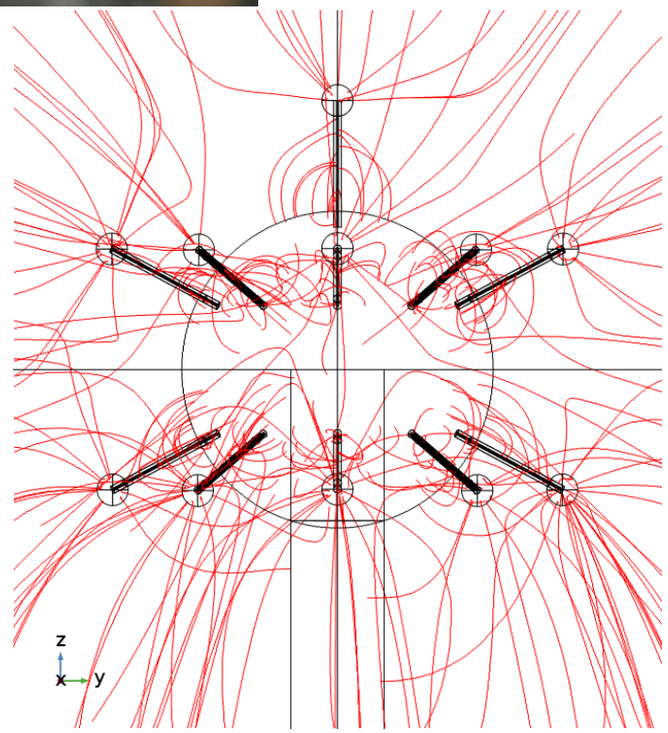
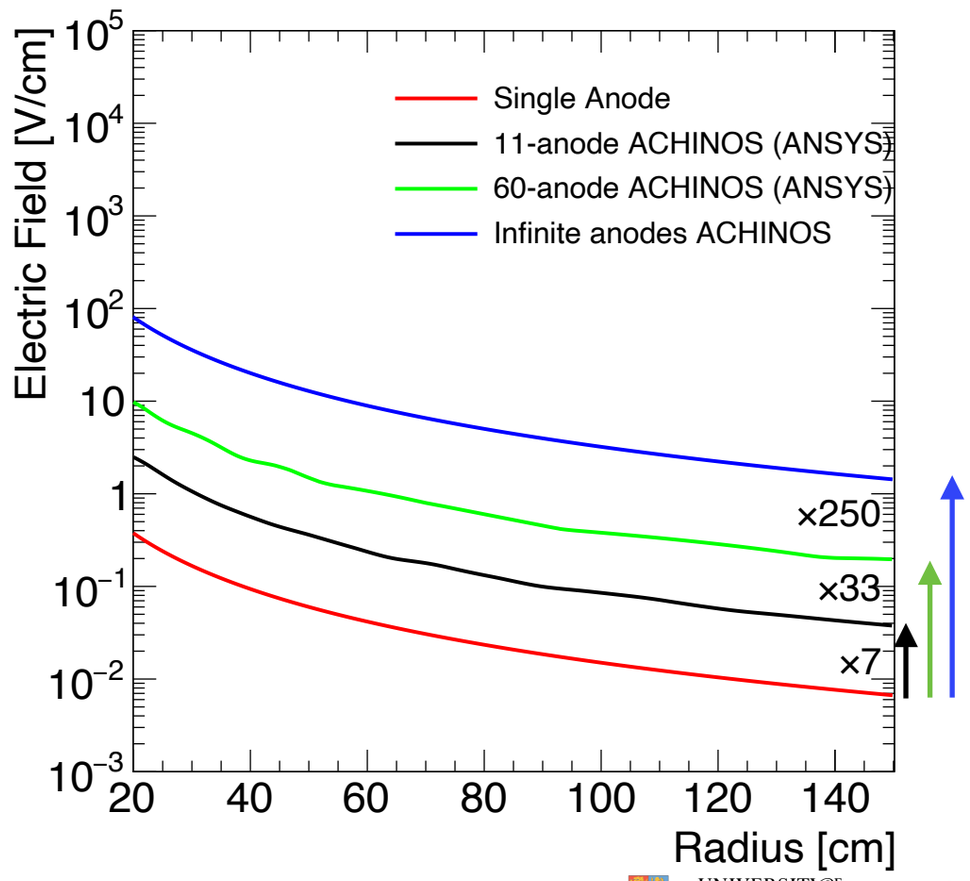
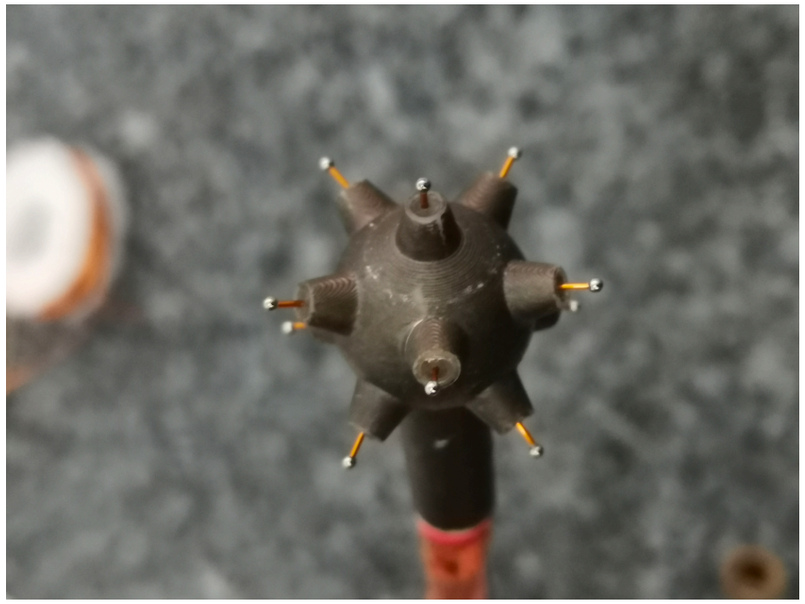
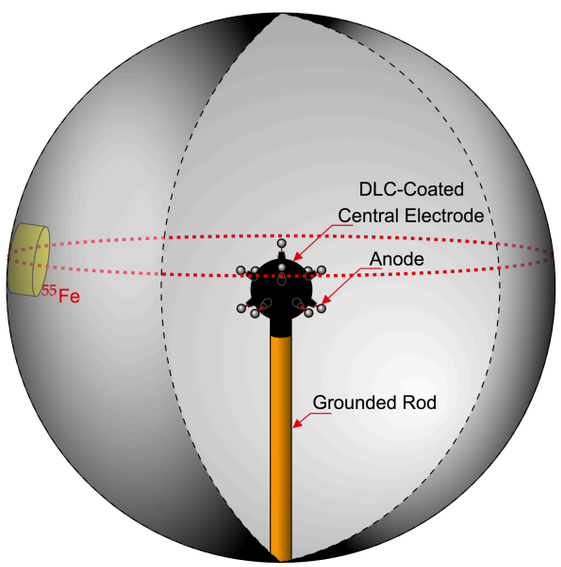




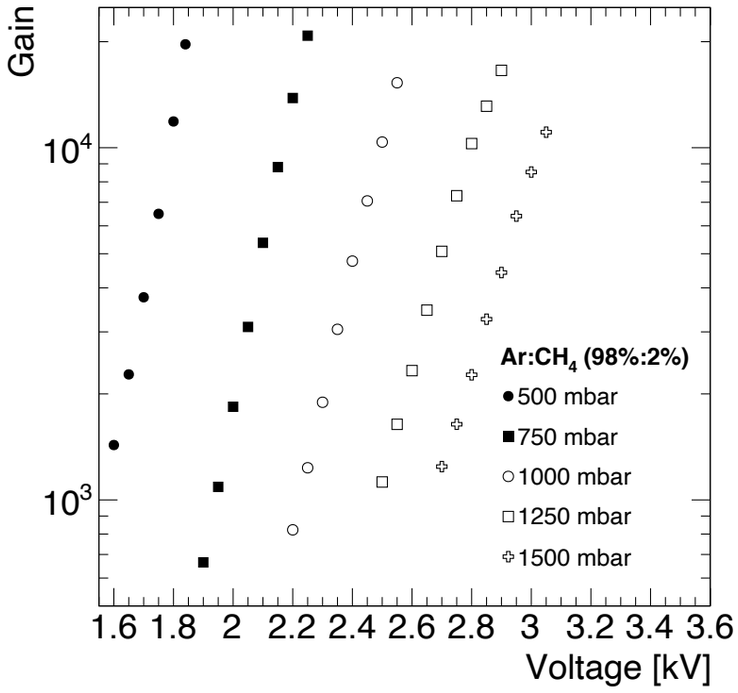
ACHINOS performance with DLC coating

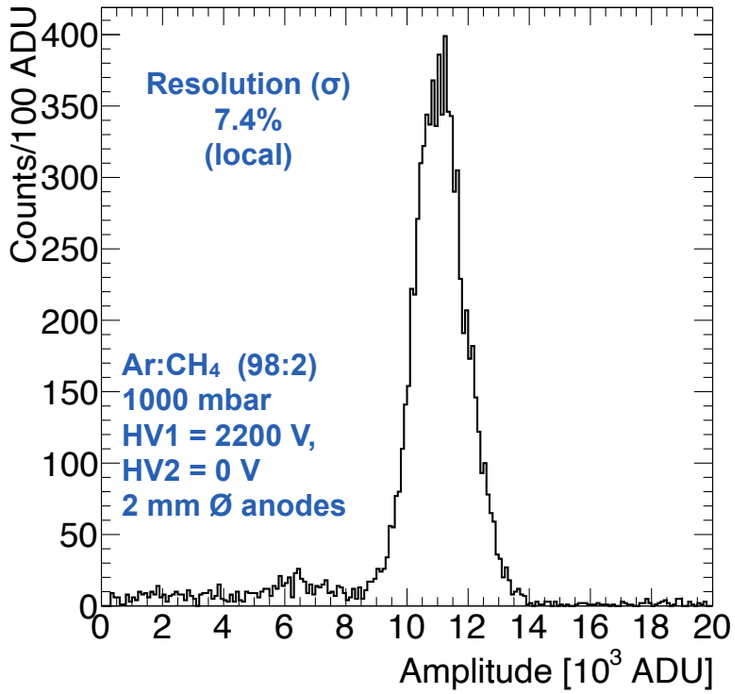


- Good energy resolution
- High pressure operation
- High gain
- Stability
- 2 channel read-out



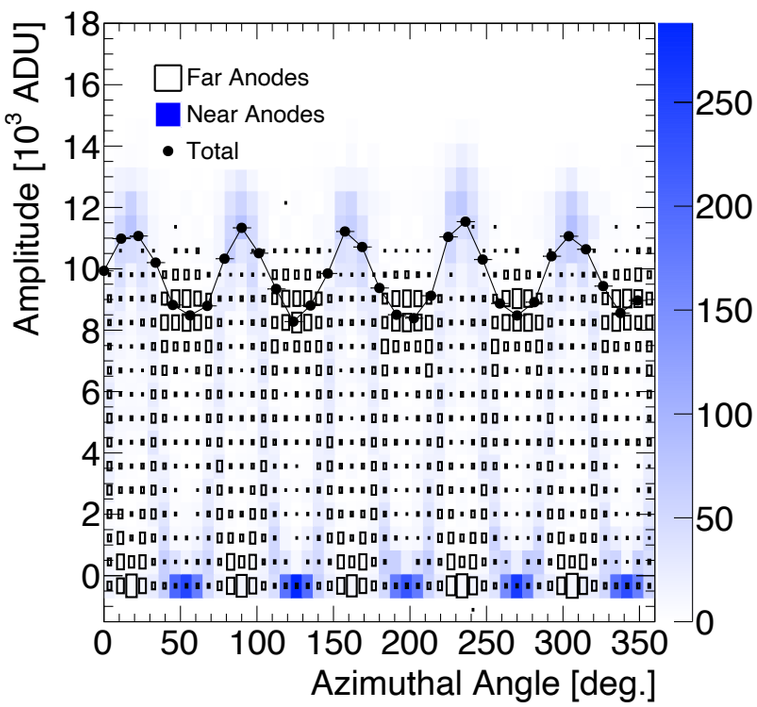
Measurement of the 5.9 keV ^{55}Fe X-ray line

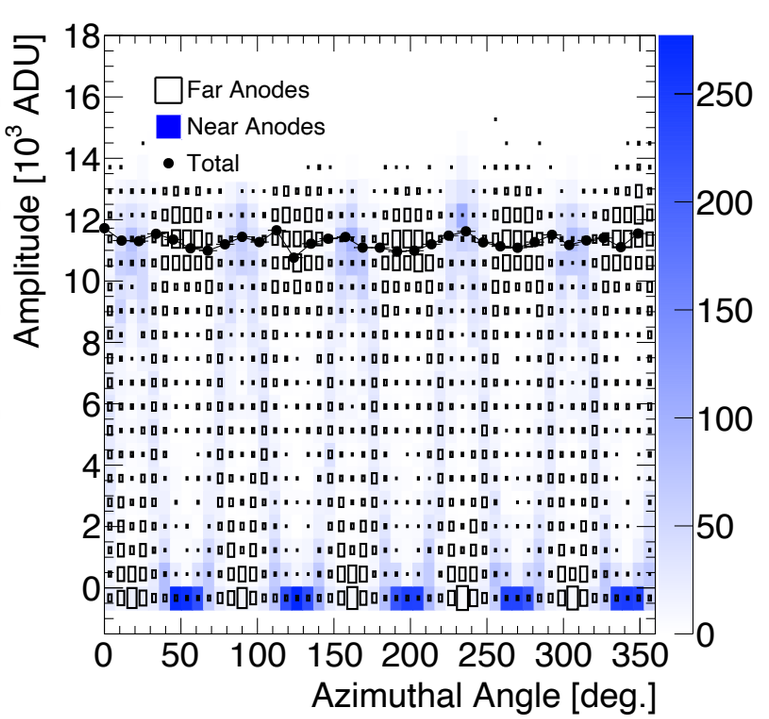




Simulations

JINST 15 (2020) 11, 11

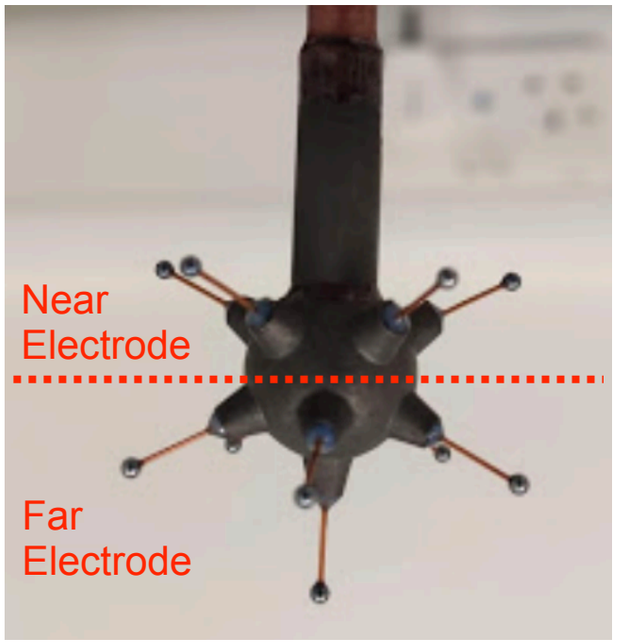


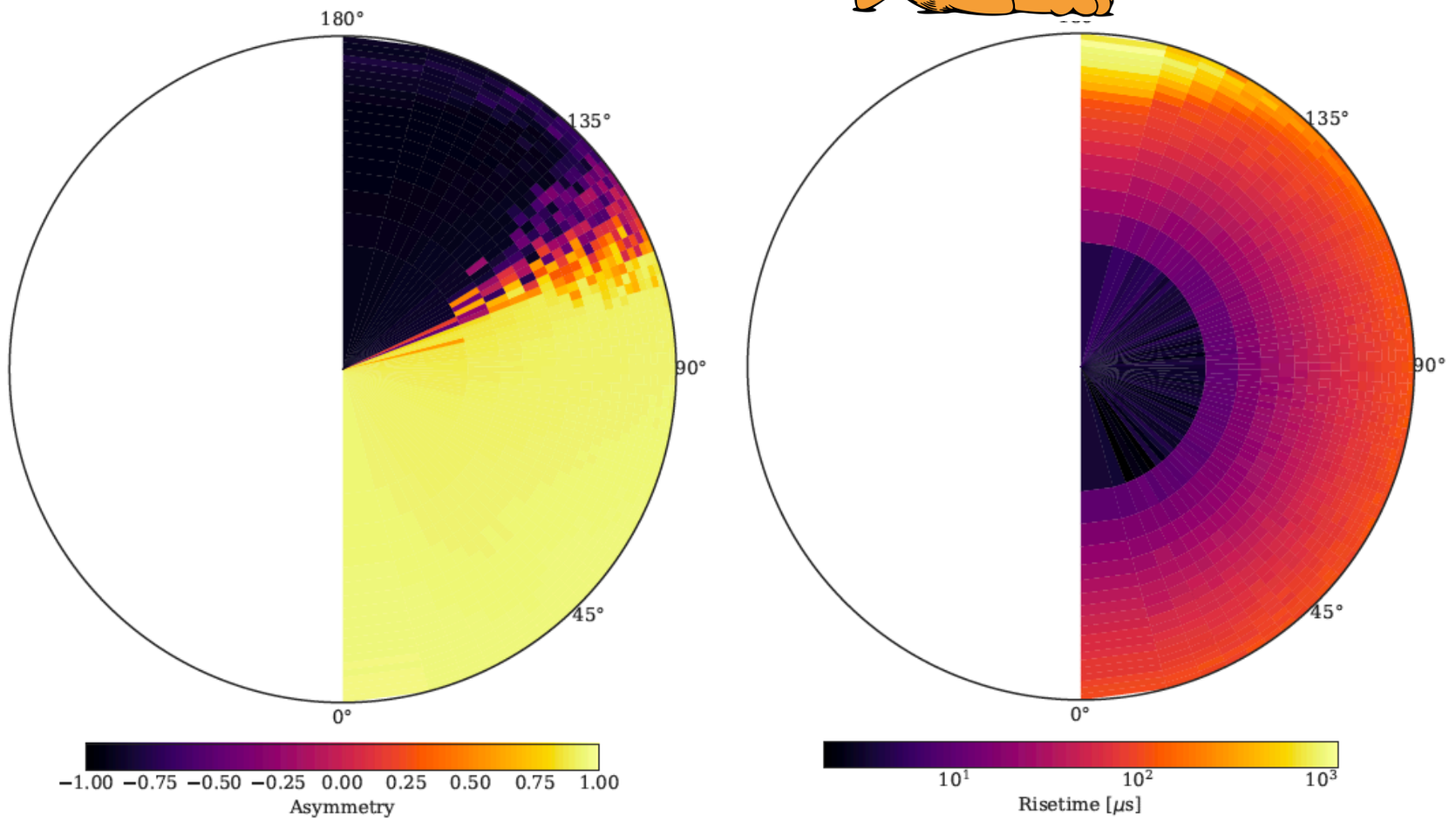


Fiducialisation

Birmingham simulation framework, combining strengths of Geant4 and Garfield++

JINST 15 (2020) 06, C06013

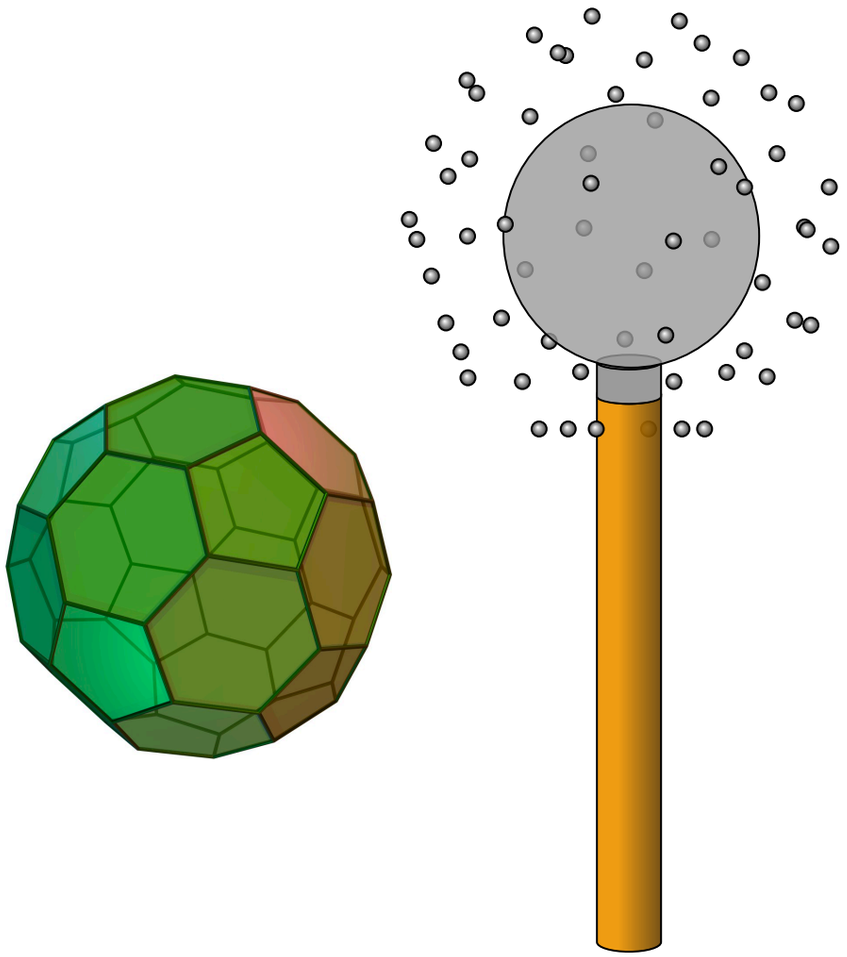




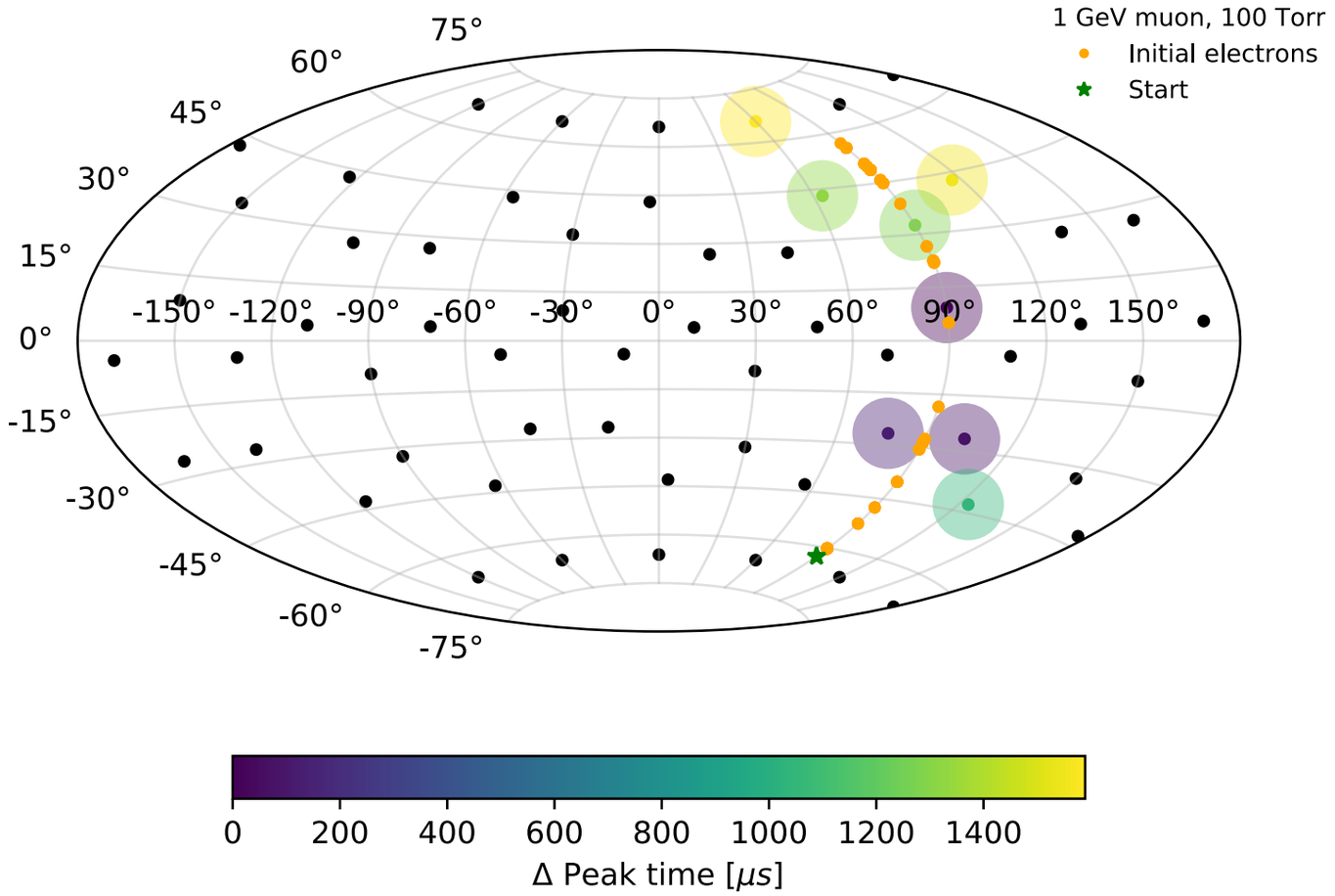
- Reading out individual ACHINOS anodes: position of interaction can be reconstructed
- First tests: Separate the anodes in two electrodes “Near” and “Far” (from the rod)
  - Asymmetry of pulse amplitudes: zenith angle
  - Pulse rise-time: radius

Event reconstruction

Individual anode read-out: track reconstruction



60-anodes (truncated icosahedron)



R2D2: R&D towards 0νββ with SPC

- Rare Decays with Radial Detector (R2D2)
  - R&D effort for 0νββ searches with SPC
- Aim towards tonne-scale ^{136}Xe with 1% FWHM at $Q_{\beta\beta}$=2.458 MeV
- Recent and future work:
  - Demonstrated energy resolution in Ar-prototype
  - Light and charge read-out
  - ☐ Demonstrate zero background
  - ☐ Demonstrate large mass operation

JINST 16 (2021) 03, P03012

R2D2 spherical TPC: first energy resolution results

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[d] *School of Physics and Astronomy, University of Birmingham, Birmingham, B15 2TT, U.K.*
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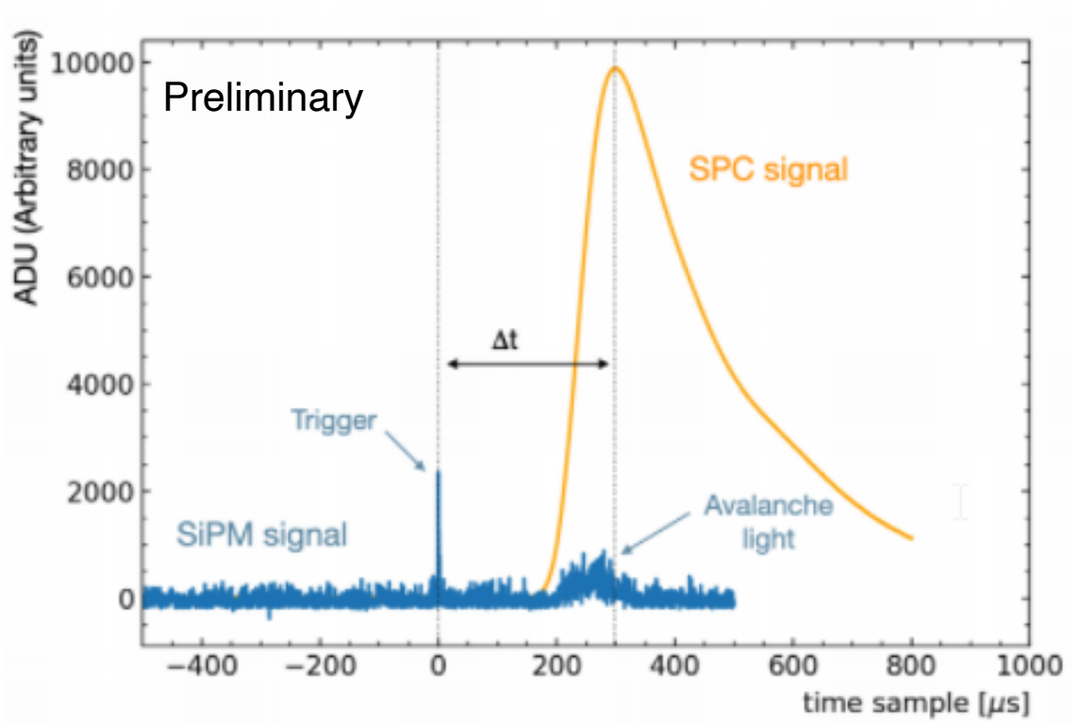
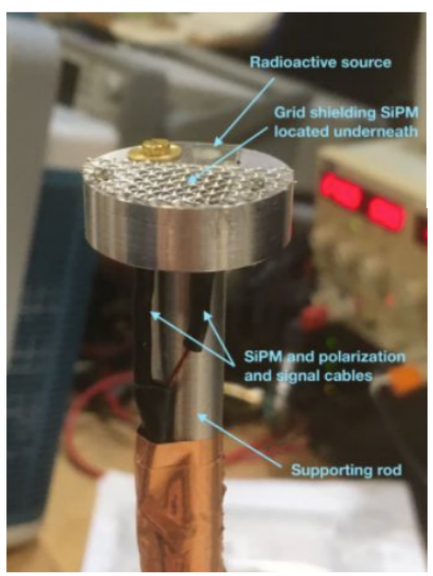




Data Simulation

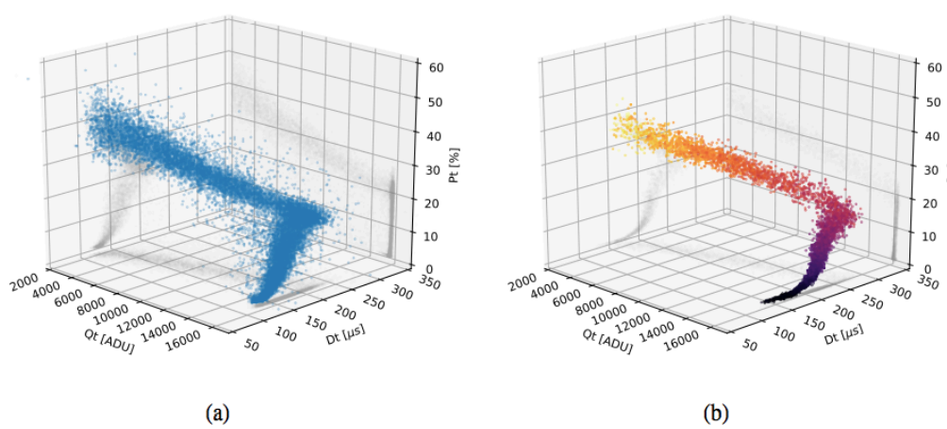


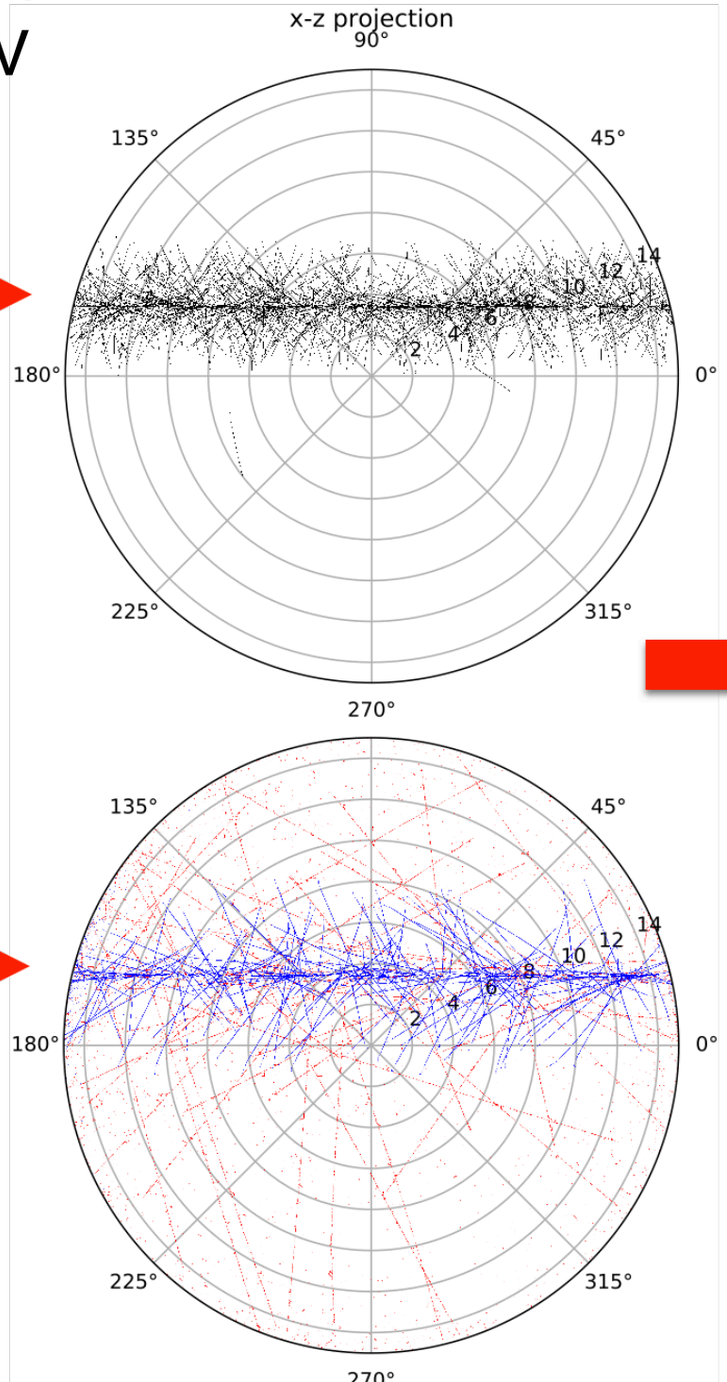
Figure 13. *(a) 3D-plot of the observables (Qt, Dt, Pt) measured for the ^{210}Po source at a pressure o 200 mbar. (b) The corresponding plot obtained from simulation, with the marker colours indicating the initial α direction, as in the previous figures.*

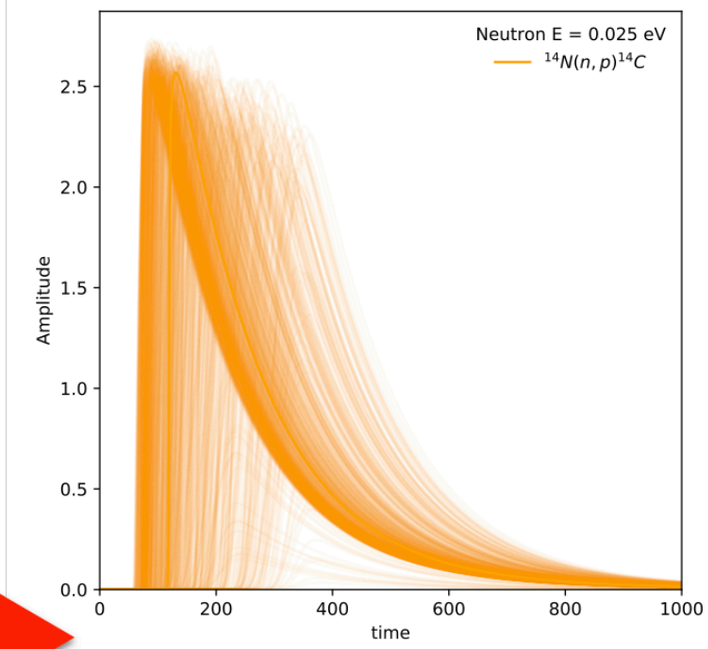
In-situ neutron measurements

- **Neutrons: critical background in DM searches**
- Underground measurements scarce
- Nitrogen gas
  - $^{14}N+n \rightarrow {}^{14}C+p$ + 625 keV
  - $^{14}N+n \rightarrow {}^{11}B+\alpha$ - 159 keV

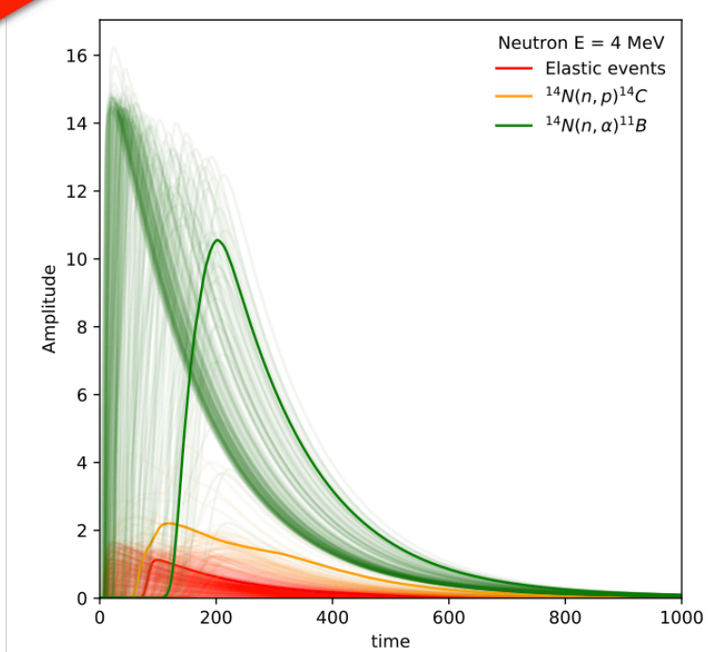
Neutron Beam
0.025 eV

Parameters
Ø30cm vessel
N_2 at 300mbar
Ø2mm anode

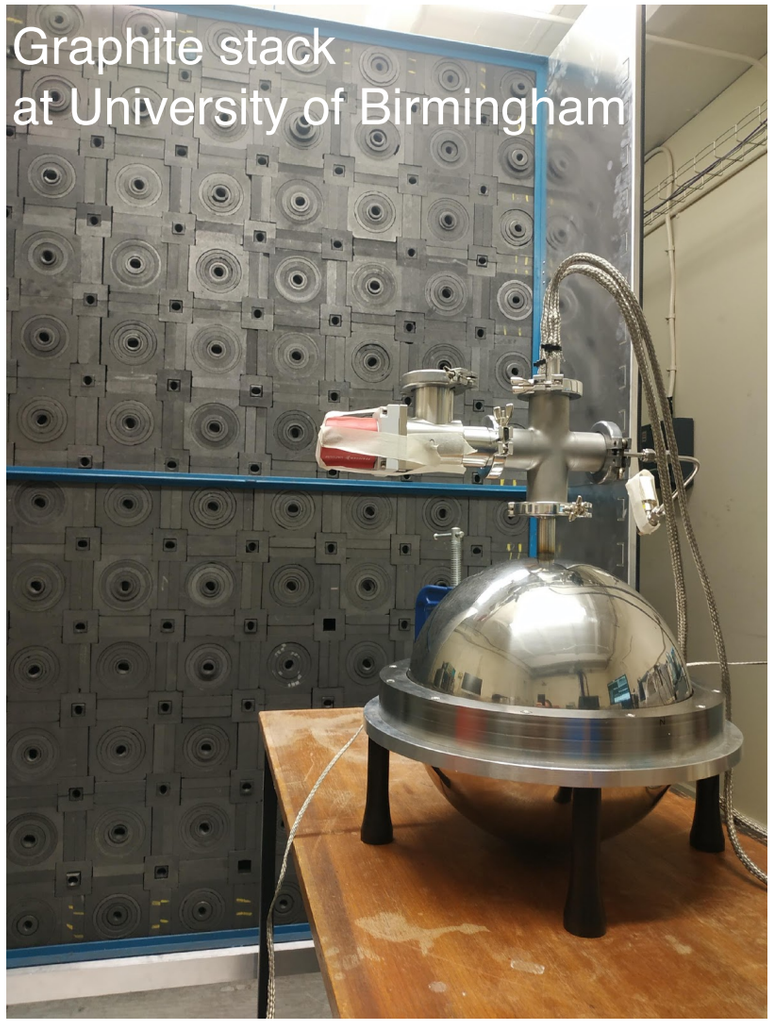


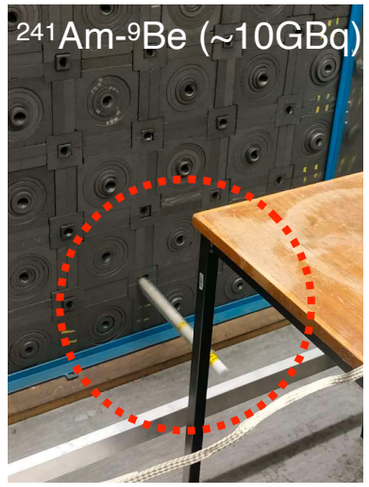


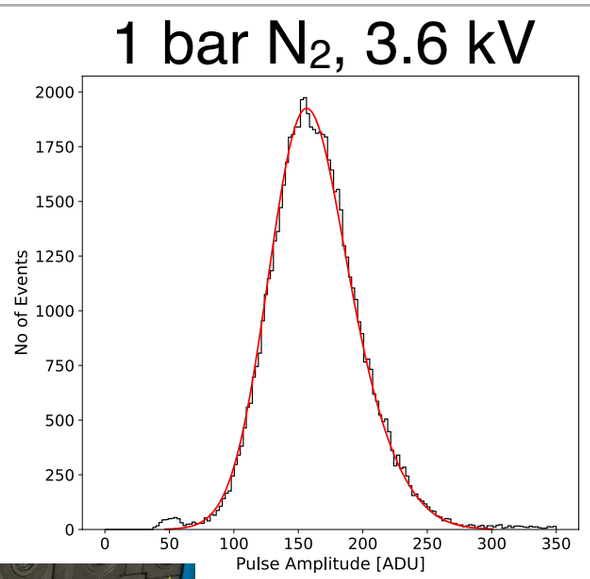
Neutron Beam
4 MeV

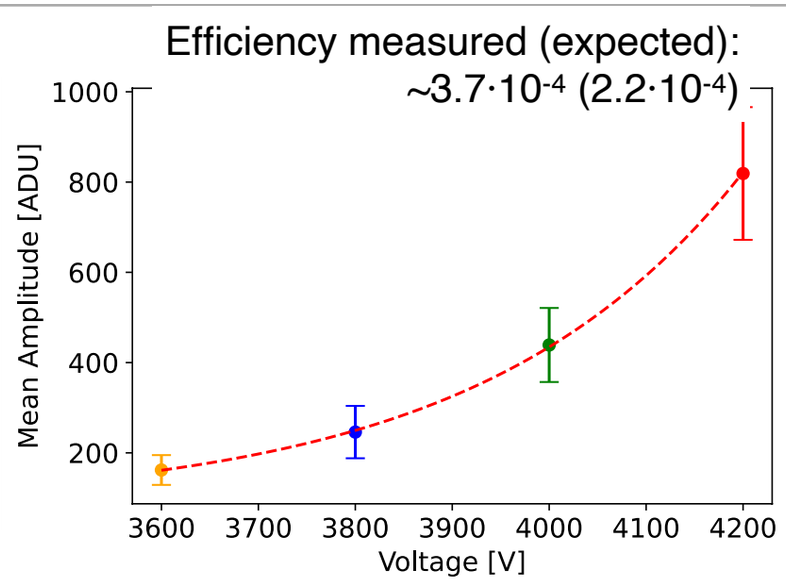


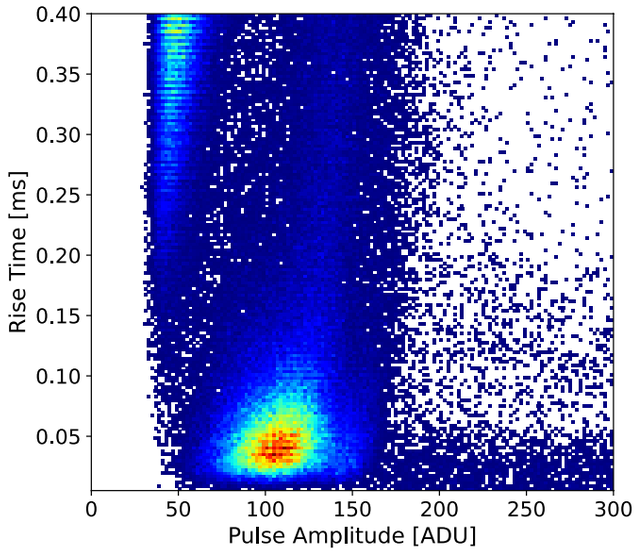
In-situ neutron measurements

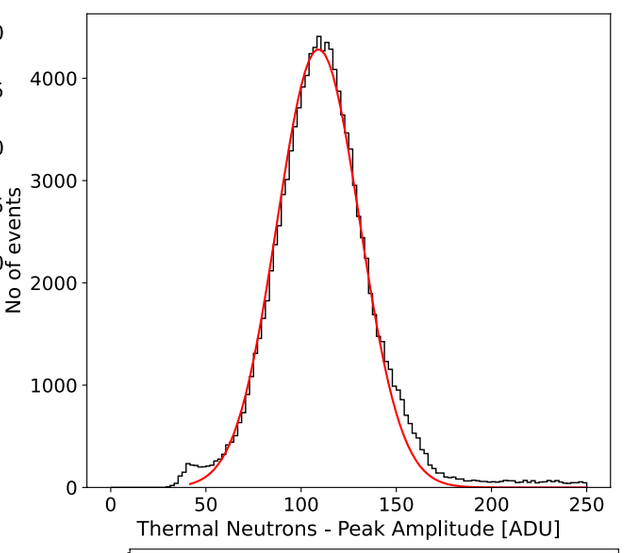






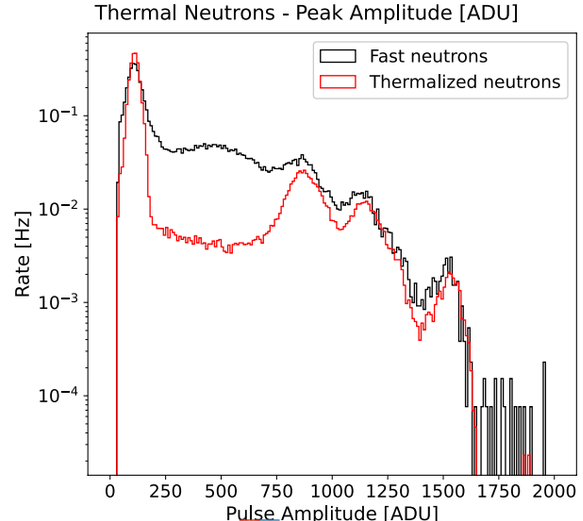






- Spherical Proportional Counter
  - ∅ 30 cm
  - N_2 gas
- Multi-anode sensor
  - 11 anodes
  - ∅ 1mm
  - 2 channel read-out

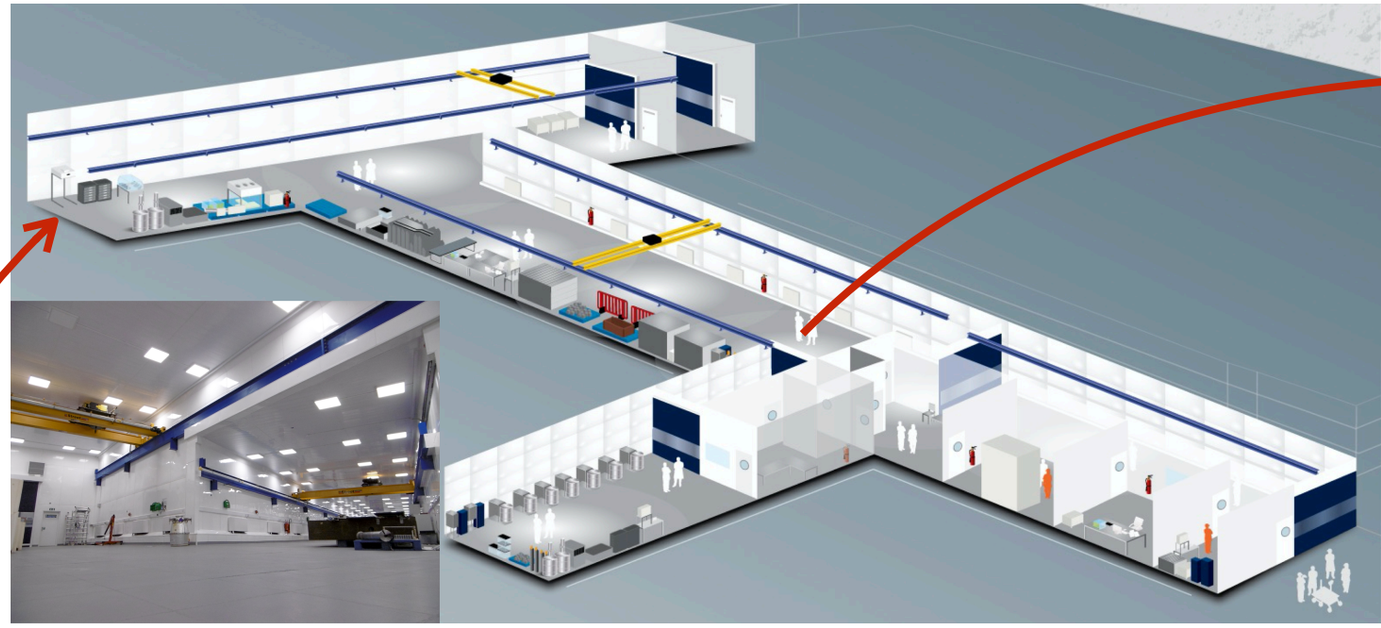
1.5 bar N_2, 4.5 kV

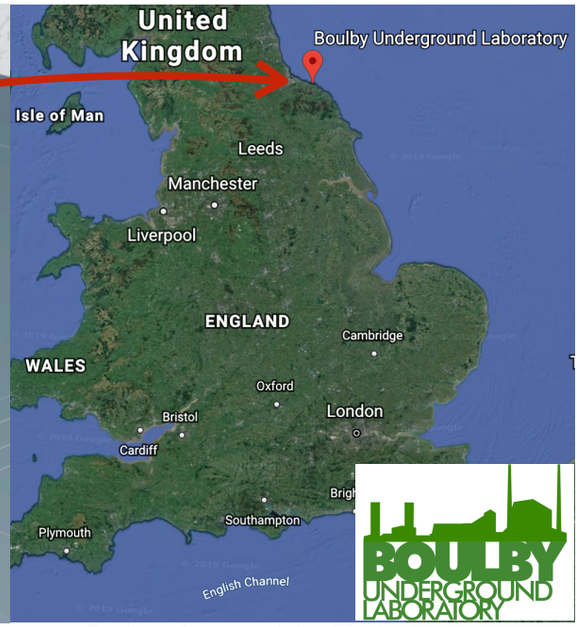


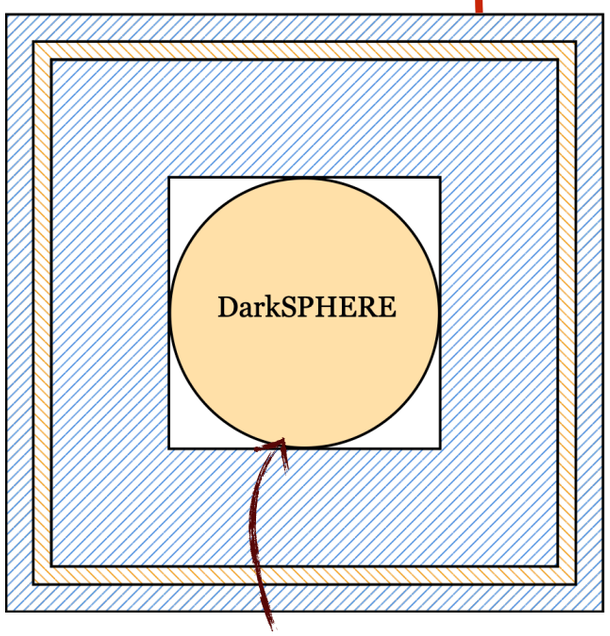
Reaching the neutrino floor

DarkSPHERE

Volume ×10: ⌀300cm intact underground electroformed spherical proportional counter
Shielding: Full water shielding option and water/lead option considered



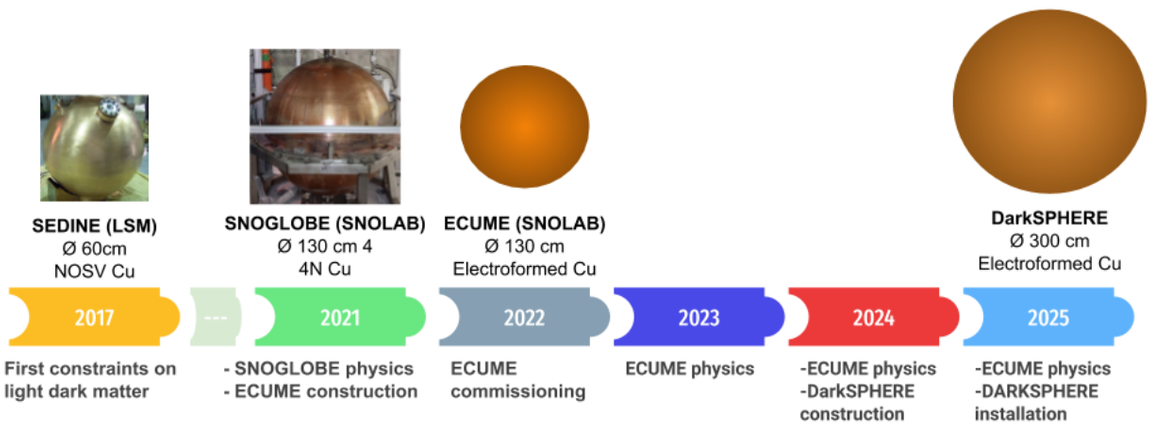




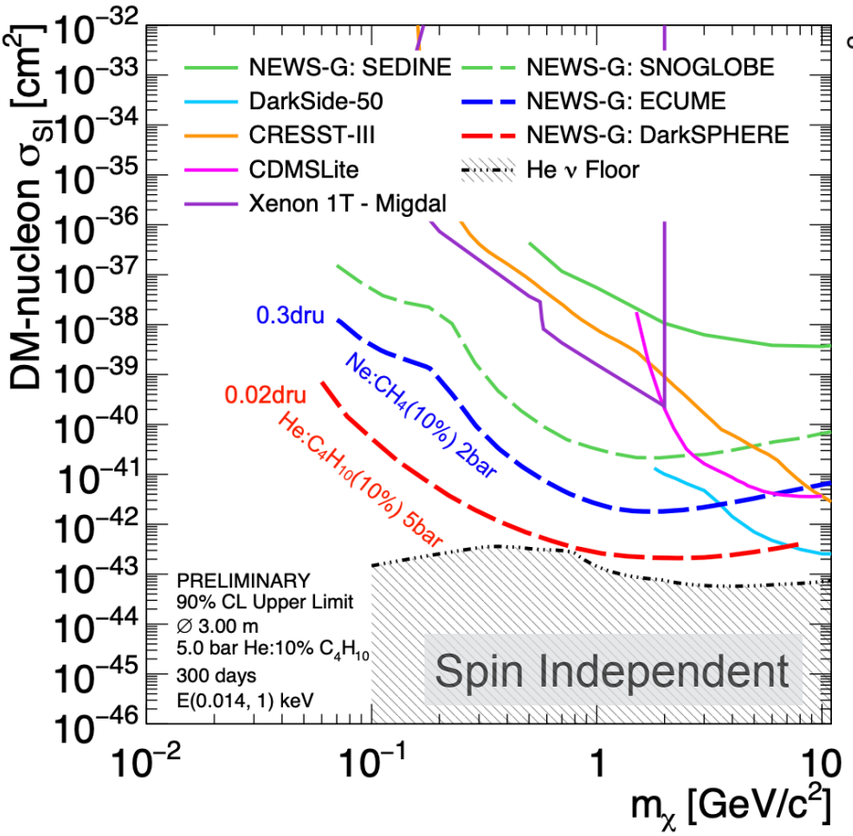
5 bar He:C_4H_{10} (90%:10%)
(27 kg target mass)

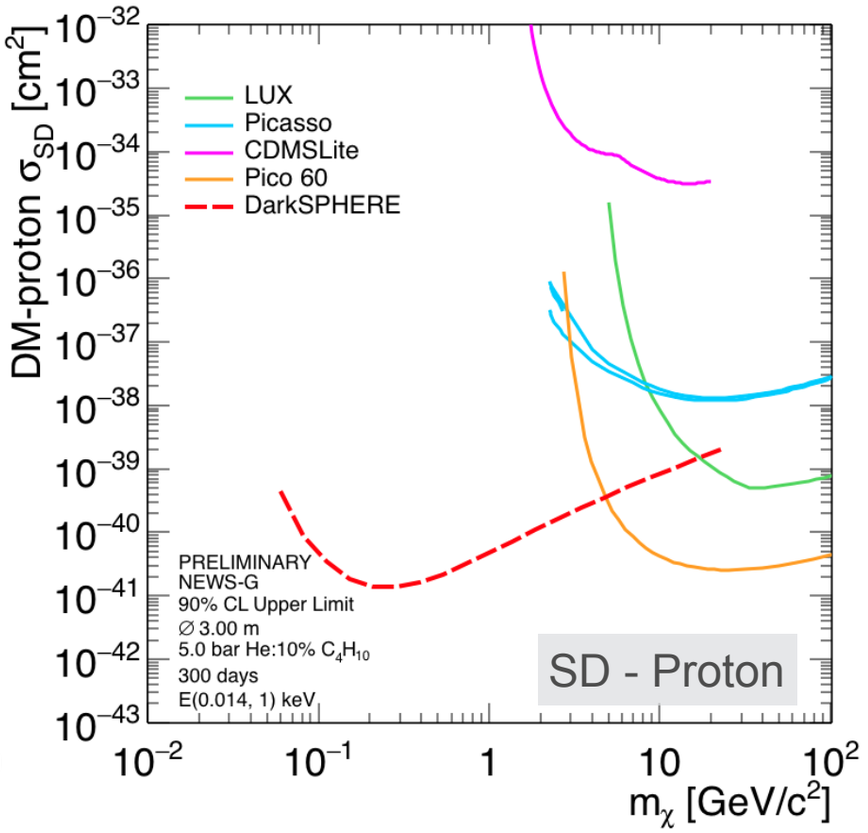
Possibility to host DarkSPHERE at Boulby's Large Experimental Cavern

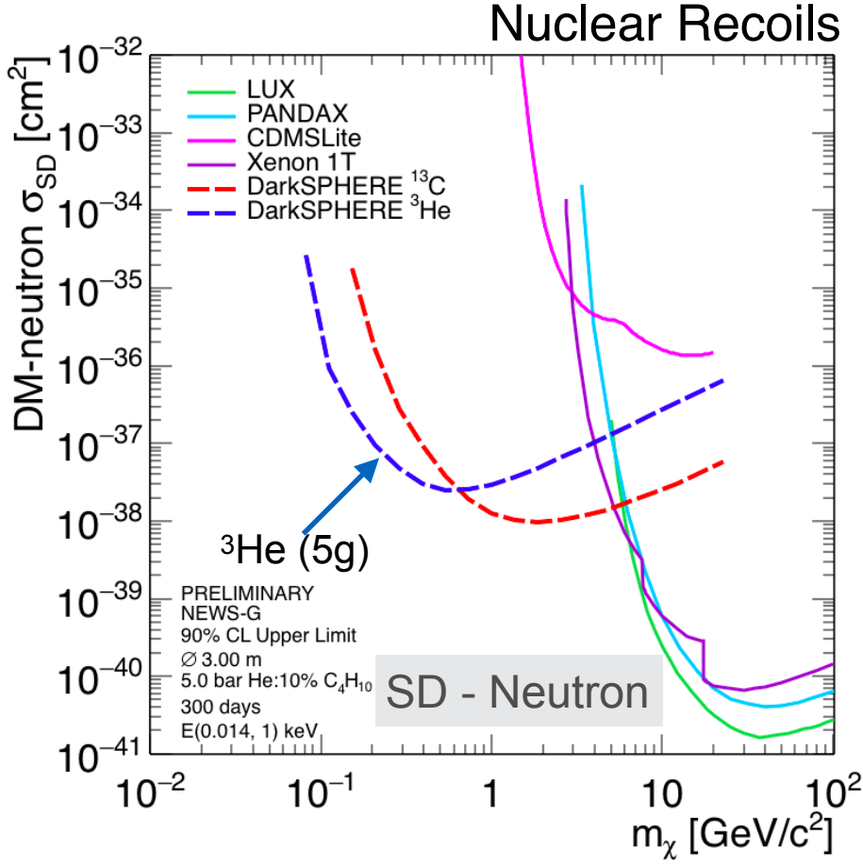
- Possibility for a 7×7×7m³ detector without further excavations
- Scoping study on possible electroformation facility on-going

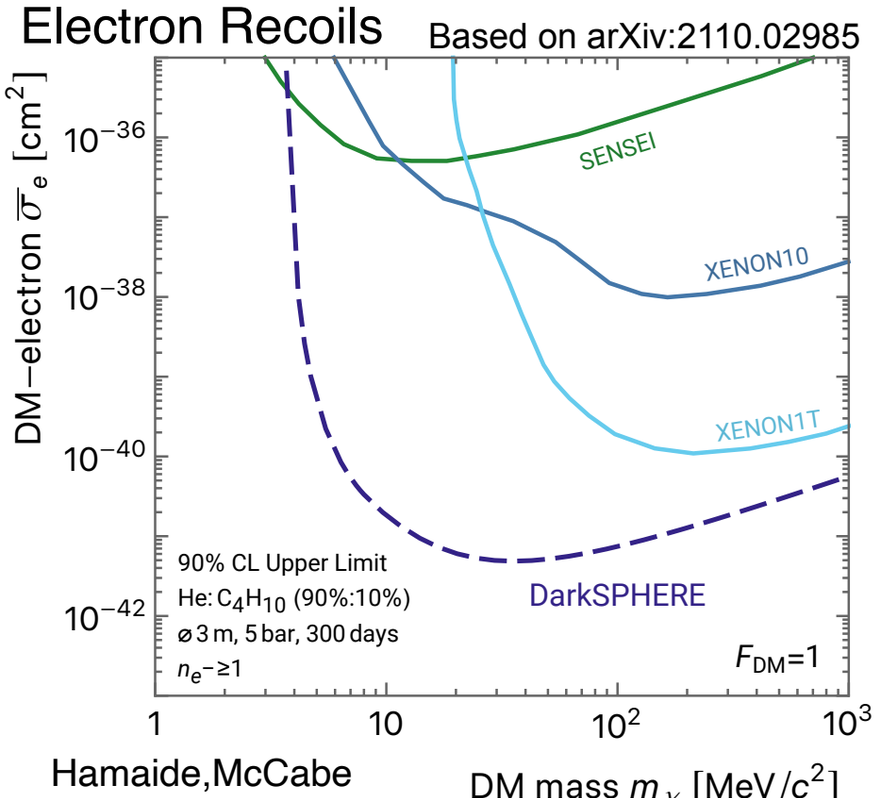


DarkSPHERE: Physics Potential









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

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

Beyond DM:

- 0νββ searches
- Neutrino physics

Potential to become a multi-physics platform

Summary

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

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

Many physics opportunities: DM Nuclear (spin dependent and independent) and electron recoils, CEvNS, axions, …