

# NEWS-G: Search for Light Dark Matter with a Spherical Proportional Counter

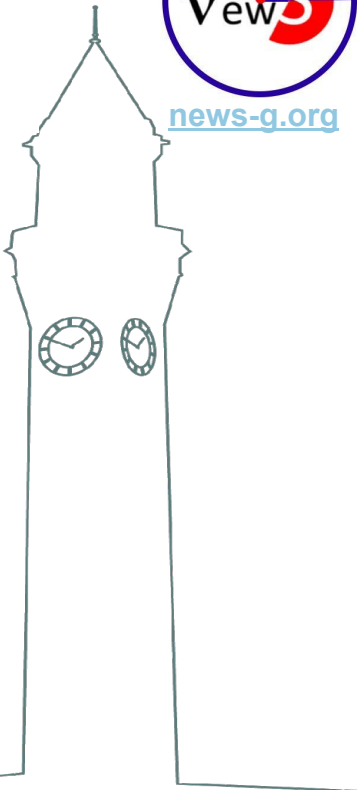
P. Knights<sup>1,2</sup>, K. Nikolopoulos<sup>1</sup>, M.-C. Piro<sup>3</sup>

*On behalf of the NEWS-G collaboration*

<sup>1</sup>*University of Birmingham, UK*

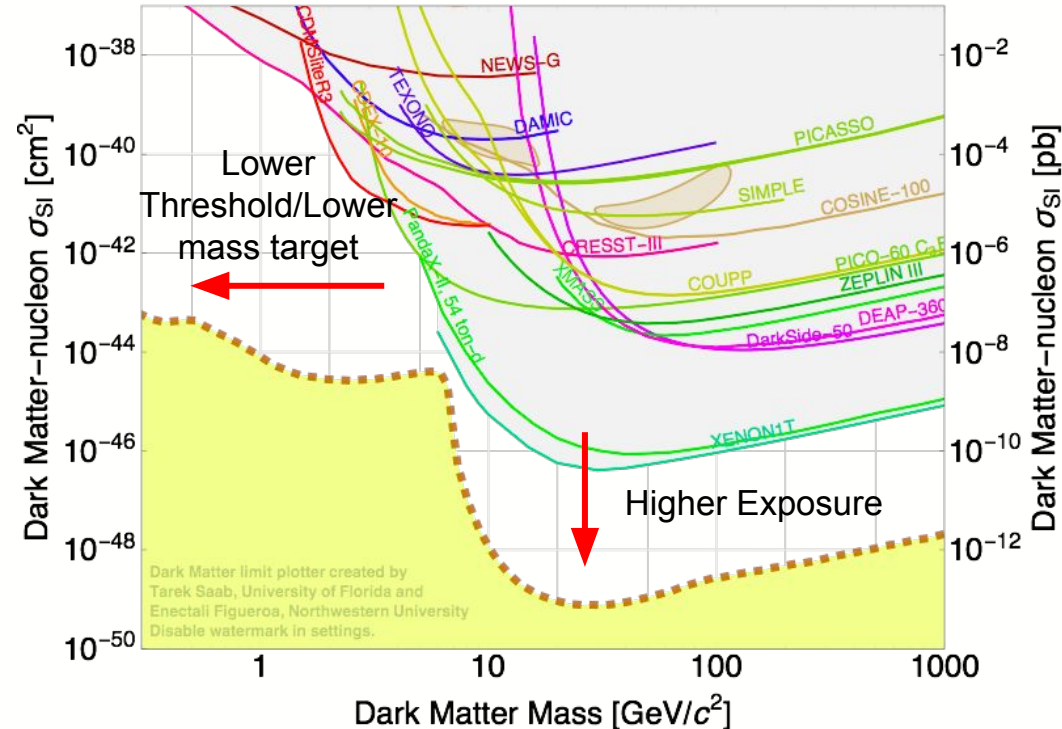
<sup>2</sup>*IRFU, CEA Saclay, France*

<sup>3</sup>*University of Alberta, Canada*

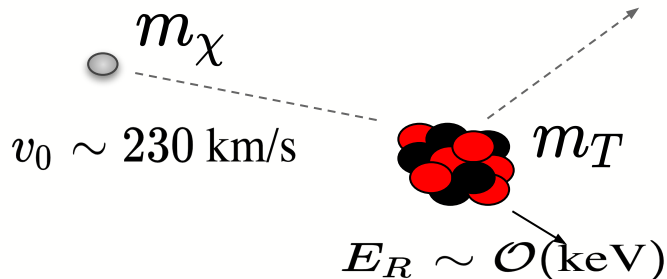


# Direct Detection Landscape

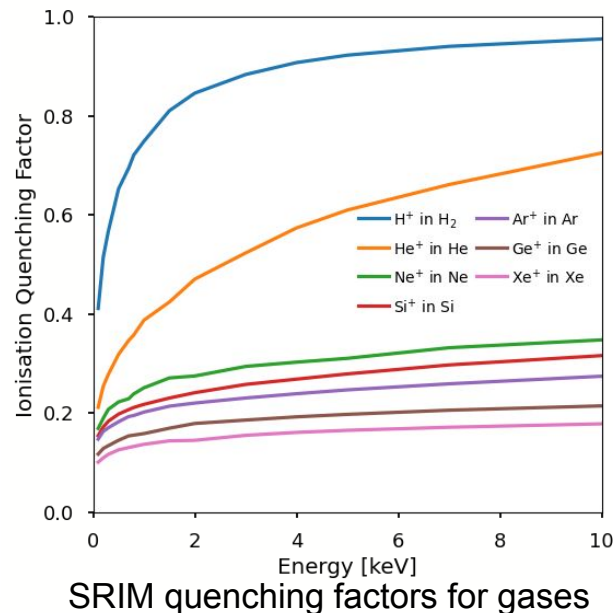
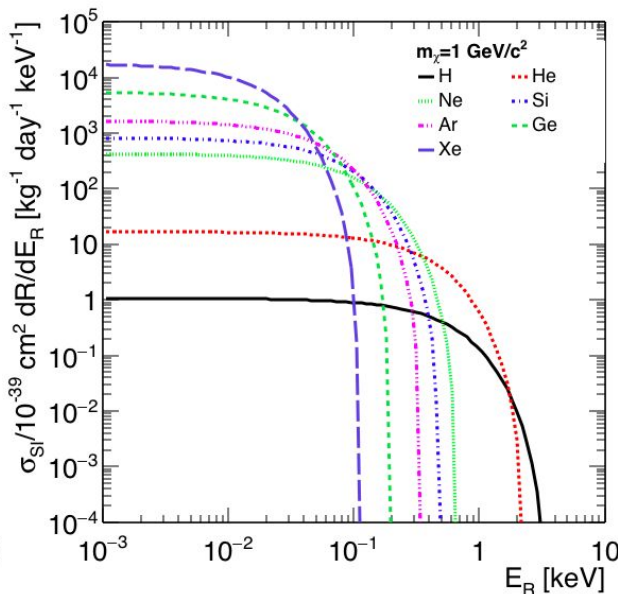
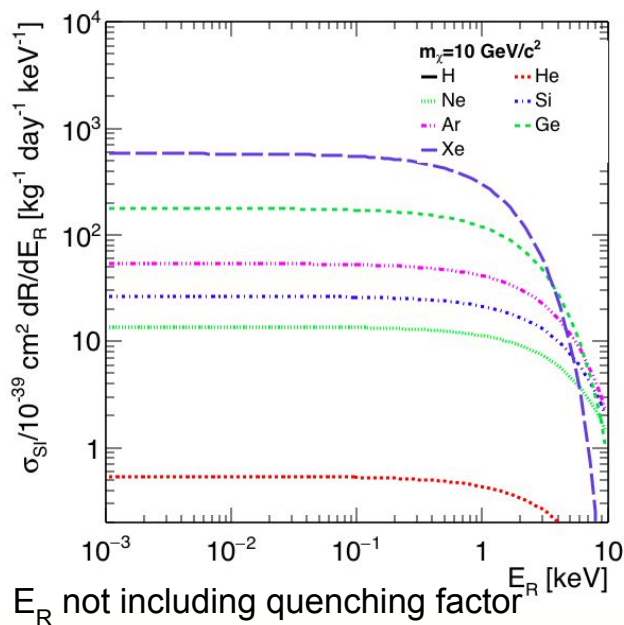
- Plethora of evidence for Dark Matter
- Absence of conclusive evidence in WIMP-preferred region
  - Lee-Weinberg Limit,  $\sim 2 \text{ GeV}/c^2$ , to  $\sim 1 \text{ TeV}/c^2$
- Much weaker constraints  $0.1\text{-}10 \text{ GeV}/c^2$  mass range
  - Region has attracted theoretical interest



# Light DM Detection



- Light DM relatively unexplored
- Requirements: Low mass target; Low energy threshold; Favourable quenching factor

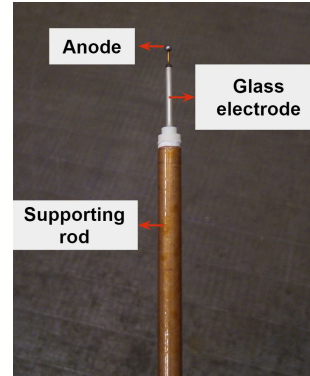


# Spherical Proportional Counter

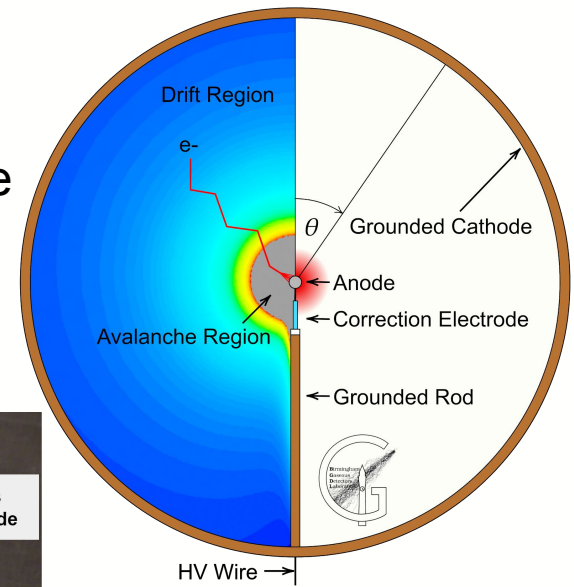
- $\varnothing\varnothing(0.1-1 \text{ m})$  sphere with  $\varnothing\varnothing(1 \text{ mm})$  sphere in centre
- Voltage applied to inner sphere - anode
- At first order,  $E \sim 1/r^2$ 
  - Naturally divides detector into drift and avalanche region
- Construction with radiopure materials
- Lowest surface-area to volume ratio
- Size independent capacitance
  - Large volume with low noise

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

$$C = 4\pi\epsilon_0 \frac{r_c r_a}{r_c - r_a} \approx 4\pi\epsilon_0 r_a \sim 1\text{pF}$$



$r_c$  = cathode radius  
 $r_a$  = anode radius



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

[I. Giomataris et al, JINST, 2008, P09007](#)

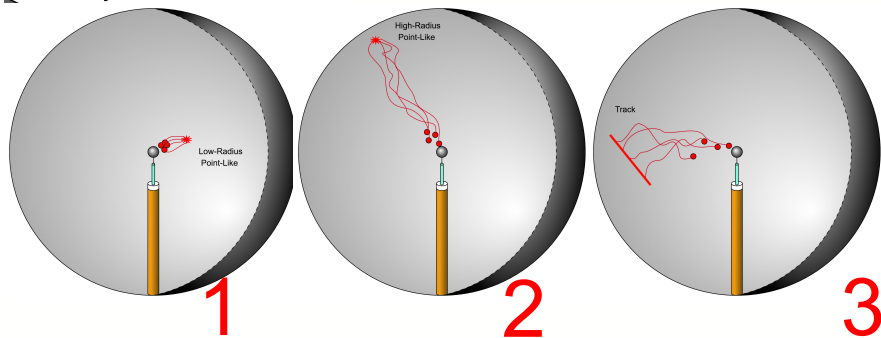
[I. Katsioulas et al, JINST, 13, 2018, no.11, P11006](#)

# Pulse-Shape Discrimination

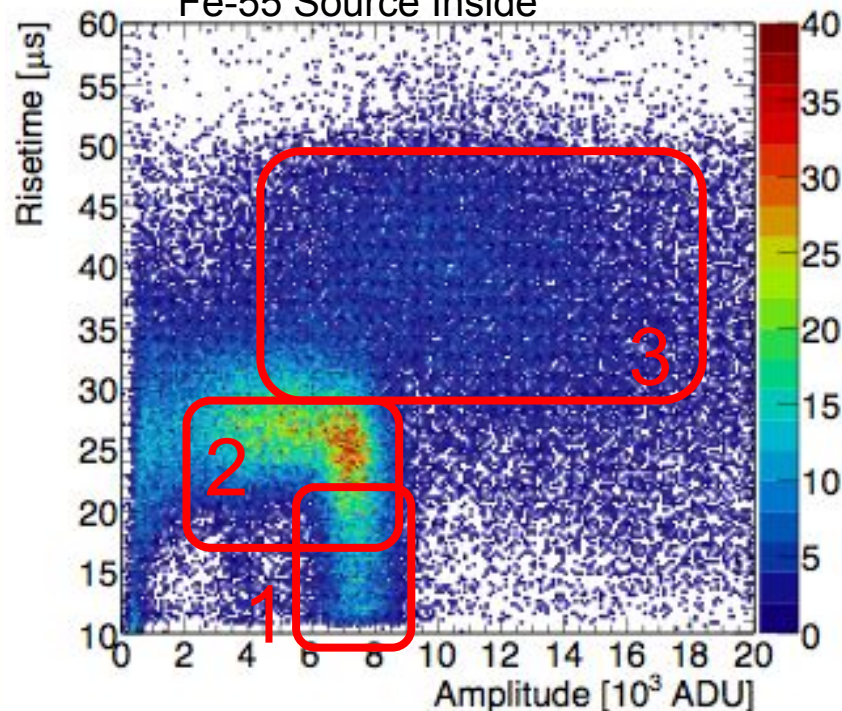
- Rise time selections to:
  - Distinguish point-like versus extended ionisations
  - Fiducialise detector
    - Majority of background from cathode material
    - Can select against near-cathode events

Primary Electron Diffusion → Rise Time of Integrated Charge →

● Primary Electron



Ø30 cm detector, 1.3 bar  
He:Ar:CH<sub>4</sub> (51.7:46%:2.3%)  
Fe-55 Source Inside



(1) X-rays in volume, (2) X-rays near cathode, (3) Cosmic Muons

# Applications

Well suited for direct Dark Matter search

- Variable gas target and pressure

- Kinematically matched to light DM

- Single channel read-out

- Potential TPC-like mode with more channels

Implemented by NEWS-G Collaboration

Many other exciting physics applications!

- Fast neutron spectroscopy [Talk: 29/07 15:30, I. Katsioulas](#)

- Neutrinoless double beta decay detection

[Talk: 30/07 13:00, A. Meregaglia](#)

- Supernova detection



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

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

<sup>a</sup> Department of Physics, Engineering Physics & Astronomy, Queen's University, Kingston, Ontario K7L 3N6, Canada  
<sup>b</sup> Pacific Northwest National Laboratory, Richland, Washington, 99354, USA  
<sup>c</sup> IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France  
<sup>d</sup> Chemistry & Chemical Engineering Department, Royal Military College of Canada, Kingston, Ontario K7K 7B4, Canada  
<sup>e</sup> Physik Department E12, Technische Universität München, James-Frank-Str. 1, Garching 85748, Germany  
<sup>f</sup> ISM, CNRS/IN2P3, Université Grenoble-Alpes, Modane, France  
<sup>g</sup> SNOlab, Liverly, Ontario, P3V 1N2, Canada  
<sup>h</sup> LFC, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France  
<sup>i</sup> Department of Physics, Aristotle University of Thessaloniki, GR-52124 Thessaloniki, Greece

Nuclear Instruments and Methods in Physics Research A 947 (2017) 10–14



Neutron spectroscopy with the Spherical Proportional Counter based on nitrogen gas

E. Bougamont<sup>a</sup>, A. Dastgheibi<sup>b</sup>, J. Derre<sup>b</sup>, J. Galan<sup>a</sup>, G. Gerbier<sup>h</sup>, I. Giomataris<sup>a</sup>, M. Gros<sup>g</sup>, I. Katsioulas<sup>b,c,d</sup>, D. Jourde<sup>e</sup>, P. Magnier<sup>g</sup>, X.F. Navick<sup>d</sup>, T. Papaevangelou<sup>d</sup>, I. Savvidis<sup>l</sup>, G. Tsileidakis<sup>g</sup>

<sup>a</sup> IRFU, Centre d'Etudes de Saclay, Gif sur Yvette, France  
<sup>b</sup> Queen's University, Kingston, Canada  
<sup>c</sup> Aristotle University of Thessaloniki, Thessaloniki, Greece



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Physics Letters B 634 (2006) 23–29

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[www.elsevier.com/locate/physletb](http://www.elsevier.com/locate/physletb)

A network of neutral current spherical TPCs for dedicated supernova detection

Y. Giomataris<sup>a</sup>, J.D. Vergados<sup>b,\*</sup>

<sup>a</sup> CEA, Saclay, DAPNIA, Gif-sur-Yvette cedex, France  
<sup>b</sup> University of Ioannina, GR-45110 Ioannina, Greece

Received 22 August 2005; received in revised form 9 November 2005; accepted 10 January 2006

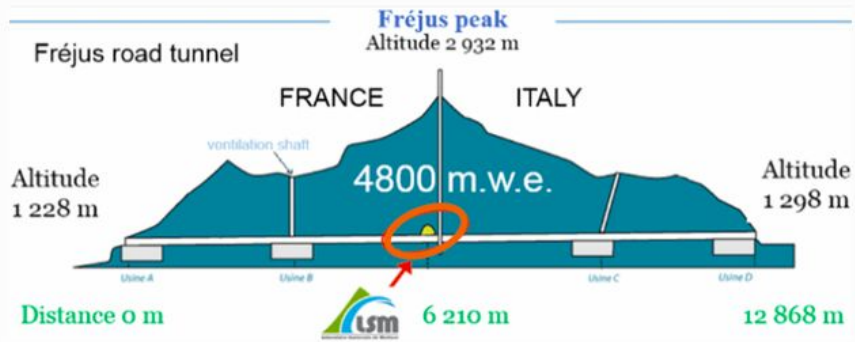
# New Experiments With Spheres-Gas: NEWS-G Collaboration



# SEDINE - First NEWS-G DM Detector

- Ø60 cm spherical proportional counter
- Using Aurubis NOSV Copper
- Several stages of chemical cleaning to remove Rn deposits
- Located in Modane Underground Lab., France

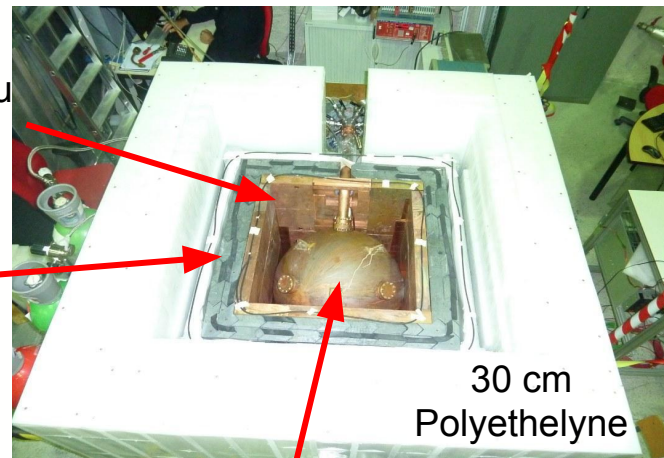
Laboratoire Souterrain de Modane (LSM)



Muon rate:  $5 \mu/m^2/day$   
c.f. Surface:  $\sim 14 \times 10^6 \mu/m^2/day$



Ø6.3 mm Anode

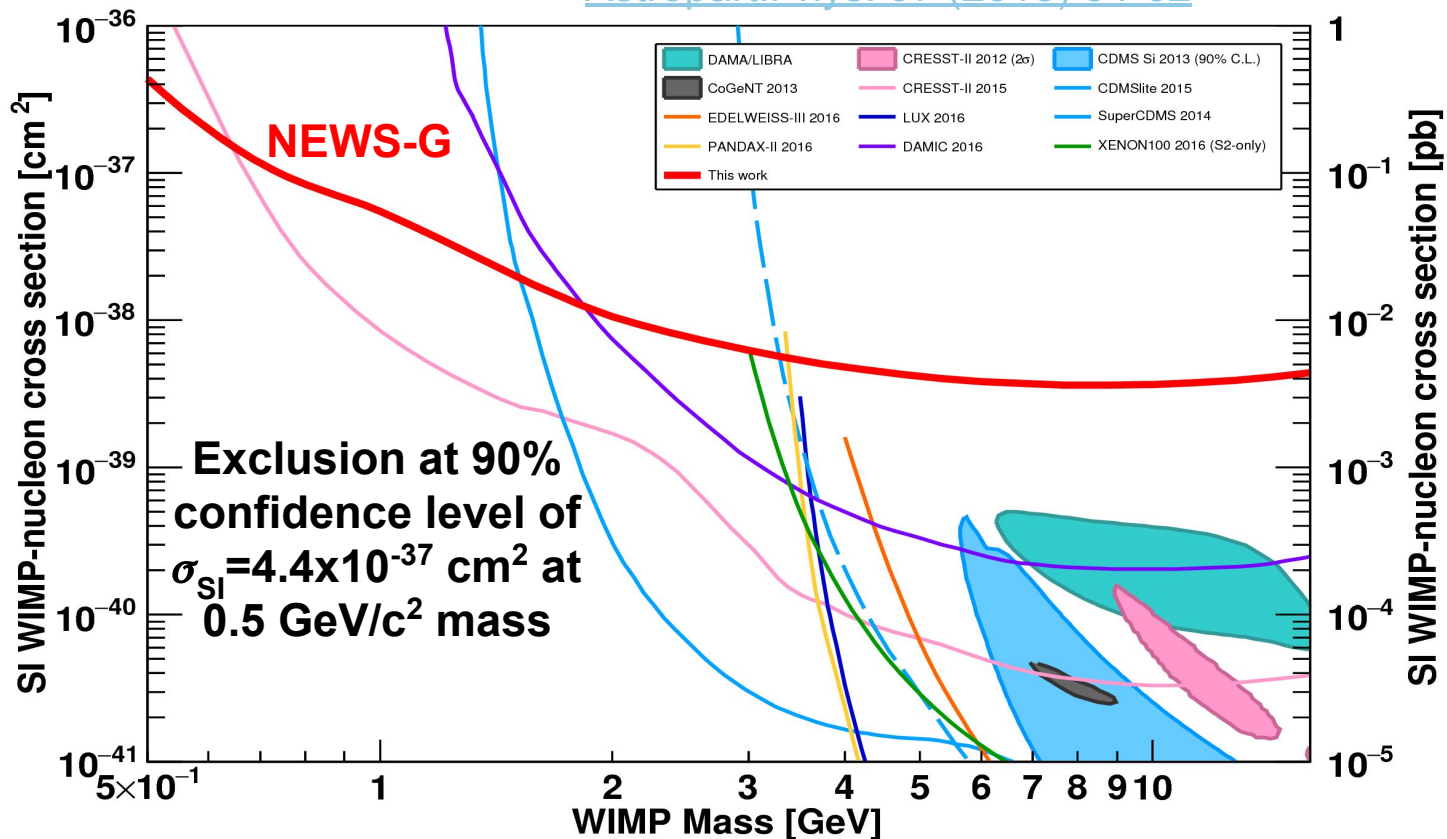




# First Results

- **Gas:** Ne:CH<sub>4</sub>  
(99.3:0.7%)
- 3.1 bar: 282 g
- 34.1 live-days
- **9.6 kg/days exposure**

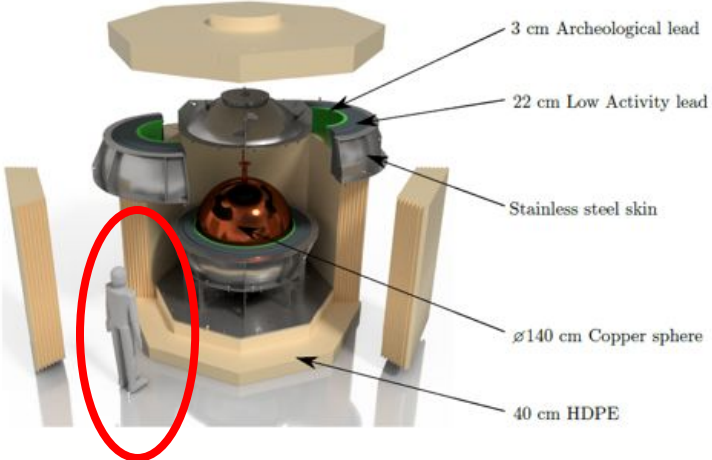
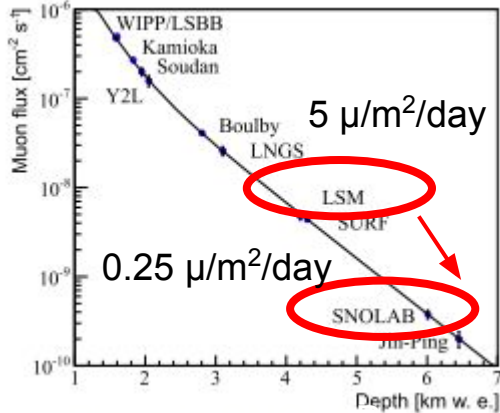
[Astropart.Phys. 97 \(2018\) 54-62](#)



Standard assumptions on WIMP velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM

# NEWS-G at SNOLAB

- Next stage of NEWS-G
- Ø130 cm detector - Bigger
- 4N (99.99% pure) Aurubis copper - More radio-pure
  - ~7-25 µBq/kg Th and ~1-5 µBq/kg U
- Operated in both LSM and SNOLAB



Spinning



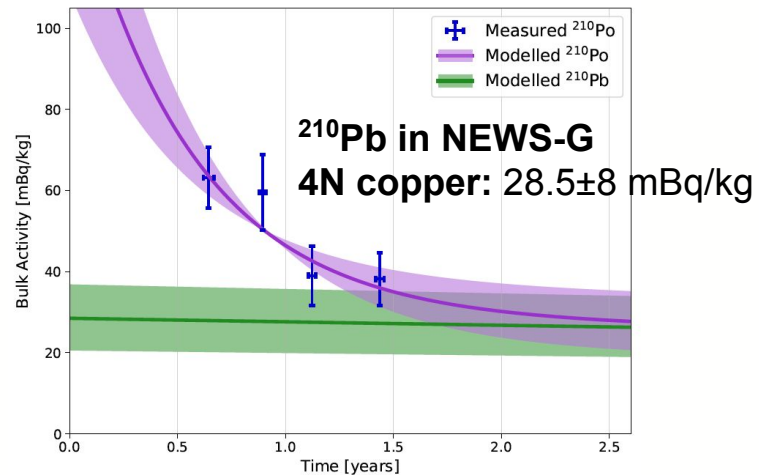
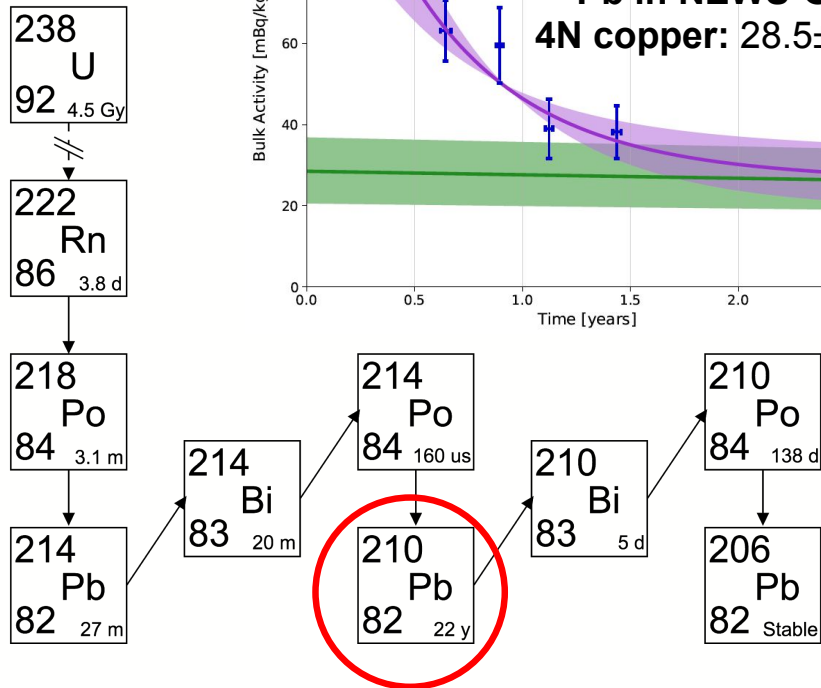
# Background Contributions in Copper

- $^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$  by fast neutrons from cosmic muon spallation
- $^{238}\text{U}$  and  $^{232}\text{Th}$  decay chain
  - Naturally found and **deposited by  $^{222}\text{Rn}$** 
    - measured directly by mass spectroscopy
    - Infer progeny activities
  - Recent development: **measure  $\alpha$ -particle from  $^{210}\text{Po}$  decay directly**
  - $^{210}\text{Pb}$  activity inferred from  $^{210}\text{Po}$

XIA UltraLo-1800



[NIM A884 \(2018\) 157-161](#)

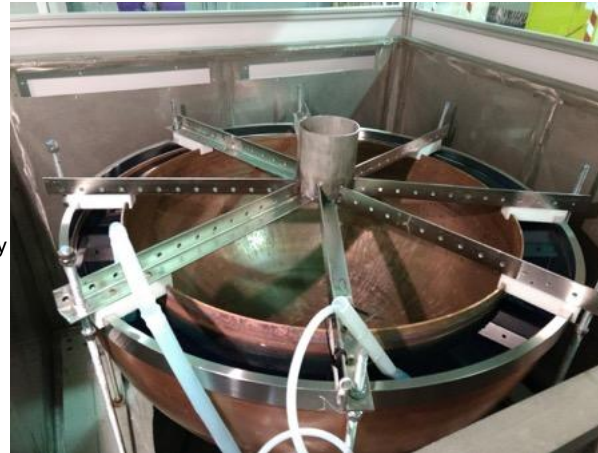
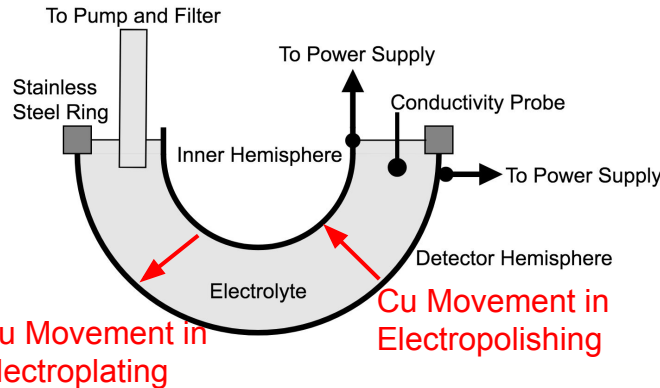
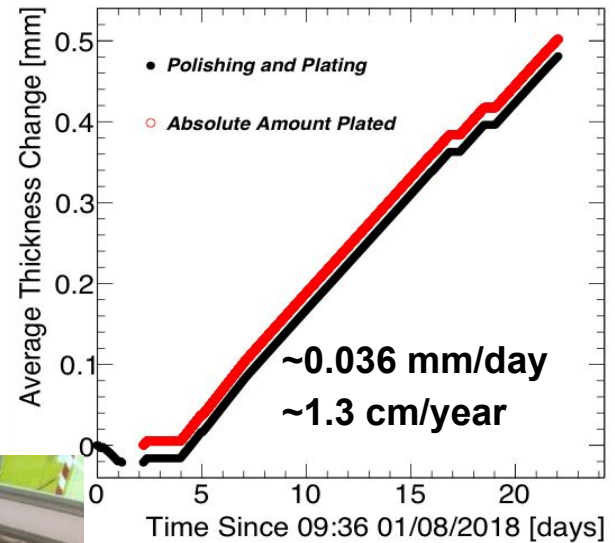


# Electroplating

## ■ Electroplating Copper

- ‘High reduction potential’ of copper
- **Preferentially deposited in electroplating**
- Used to apply 500 μm ultra-pure inner layer
- Reduce background rate below 1 keV by 70%

Reductants	Oxidants	$E^0$ (V)
$\text{Cu}^{2+} + 2e^- \rightleftharpoons \text{Cu}$	Cu	+0.34
$\text{Pb}^{2+} + 2e^- \rightleftharpoons \text{Pb}$	Pb	-0.13
$\text{U}^{3+} + 3e^- \rightleftharpoons \text{U}$	U	-1.80
$\text{Th}^{4+} + 4e^- \rightleftharpoons \text{Th}$	Th	-1.90
$\text{K}^+ + e^- \rightleftharpoons \text{K}$	K	-2.93



## ICP-MS Radio-Assay Results

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

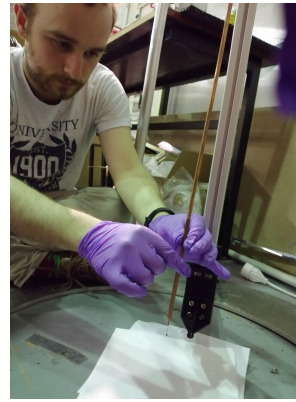
**Paper prepared for submission to NIMA “Background suppression through copper electroplating for the NEWS-G Dark Matter search”**

# Commissioning In LSM

- Detector installed in LSM
- 'Dress rehearsal' of
  - Sensor installation with glove box
  - Shielding assembly
  - Acquisition system
- First data taking
  - 135 mbar pure  $\text{CH}_4$
  - 1 bar  $\text{Ne}/\text{CH}_4$



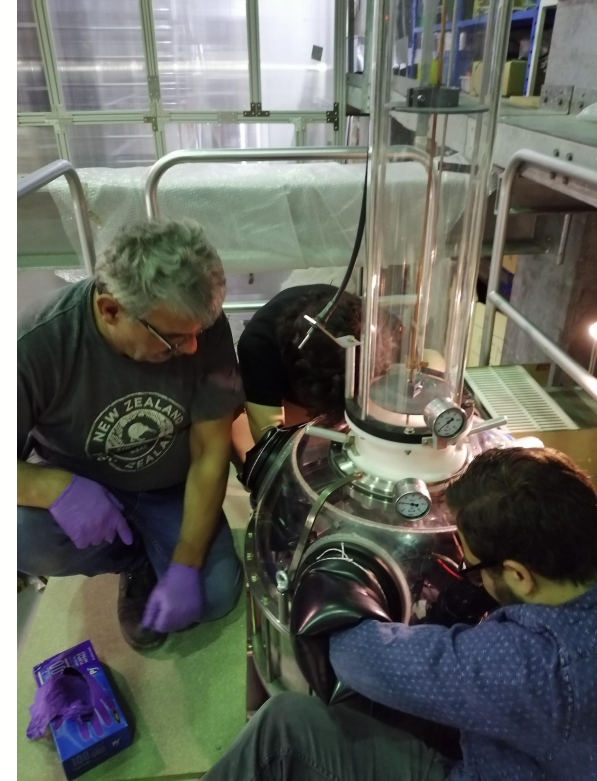
2-Channel  
Multi-Anode Sensor



Sensor Mounting to  
Rod



Sphere in half the  
lead shielding



Glove box for air-free sensor  
installation into detector

# Current Status

- Sphere in SNOLAB
  - Awaiting final chemical cleaning underground
- Platform, shielding and electronics arriving
- Beginning to put pieces together!

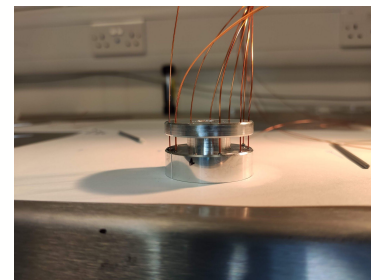
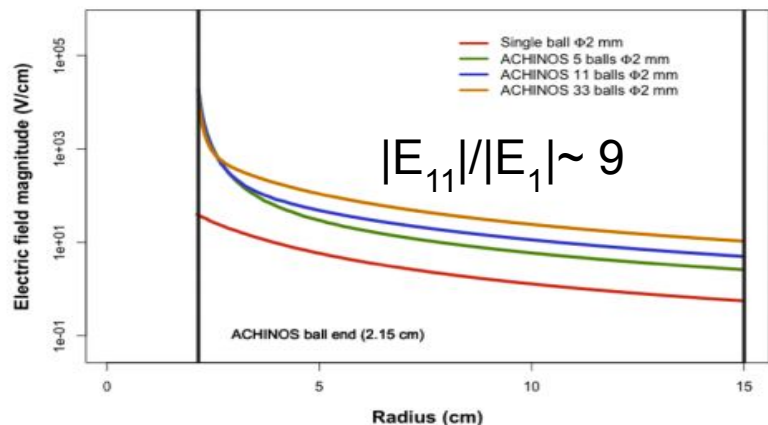


# Multi-Anode Sensor - ACHINOS

- Anodes located equidistant from centre
- Decouples gain and high-radius E-field
- Use of DLC-coating and 3D printing central electrode
- Future: Multichannel read-out and TPC-like mode

Improved Techniques:

- 3D Printing
- High-resistivity **DLC-coating**
- Smaller (<1 mm) anodes
- Precision assembly tools

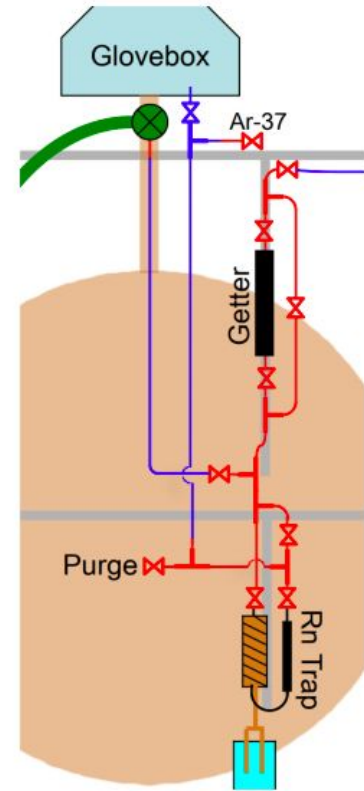


[JINST 12 P12031](#)

*Paper on recent developments under review with JINST*

# Gas Purification and Monitoring

- Oxygen and water contamination can cause attachment of primary electrons
  - More of a problem as detector size increases
- Filter gas
  - Getters are a source of radon
- Use Rn trap in series
  - Rn trap also remove  $\text{CH}_4$
- Various techniques being explored for both filtering stages and online gas quality monitoring in recirculation system
  - Tests ongoing!

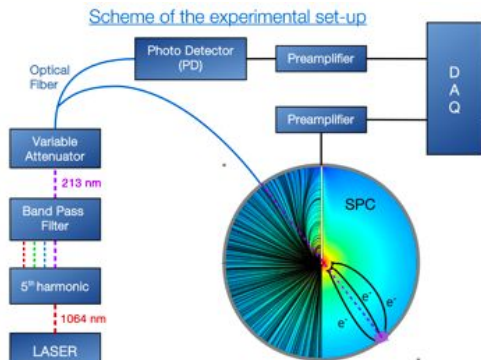


Proposed gas handling system for  
NEWS-G

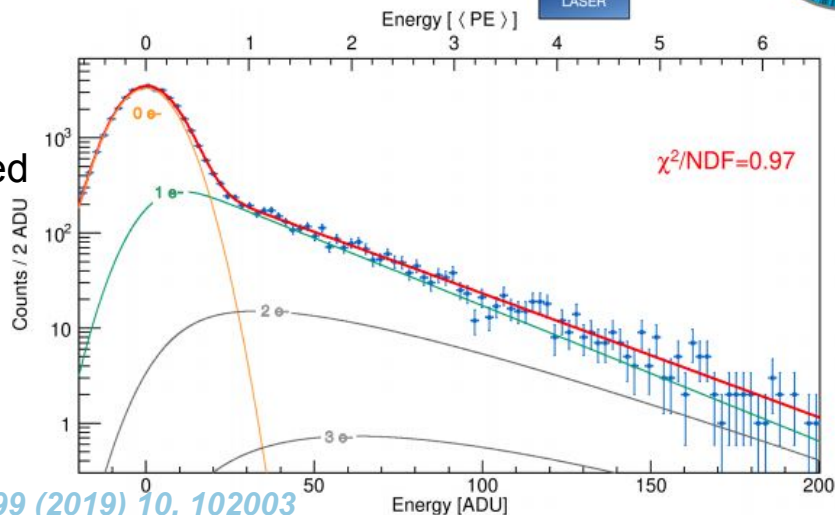


# Laser Calibration

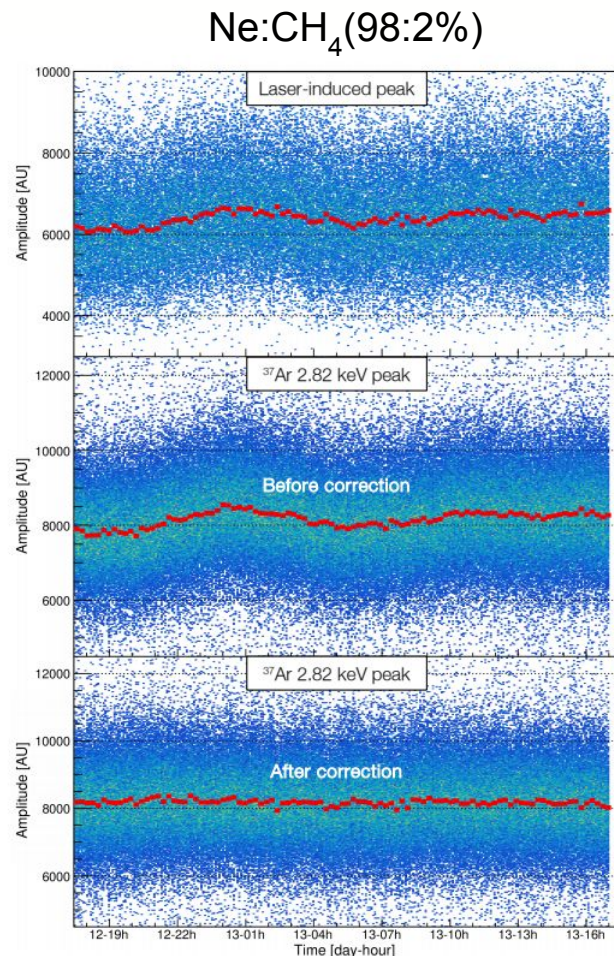
- 213 nm laser directed inside
  - Gain monitoring during data taking
  - Single-electron response
  - Gas property parameterisation



Energy spectrum of laser-induced events  
Blue=Data  
Red=Fit

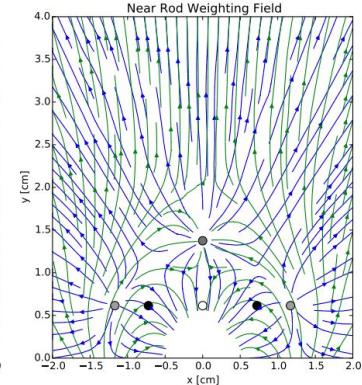
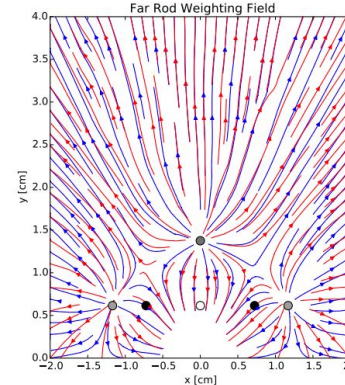
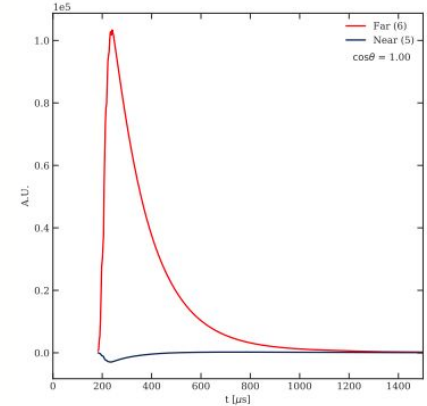
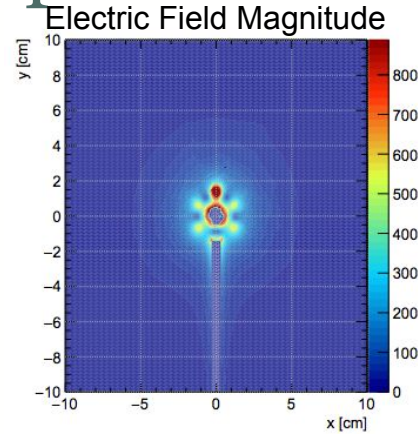


[Phys. Rev. D 99 \(2019\) 10, 102003](https://arxiv.org/abs/1905.02003)



# Simulation of the Spherical Proportional Counter

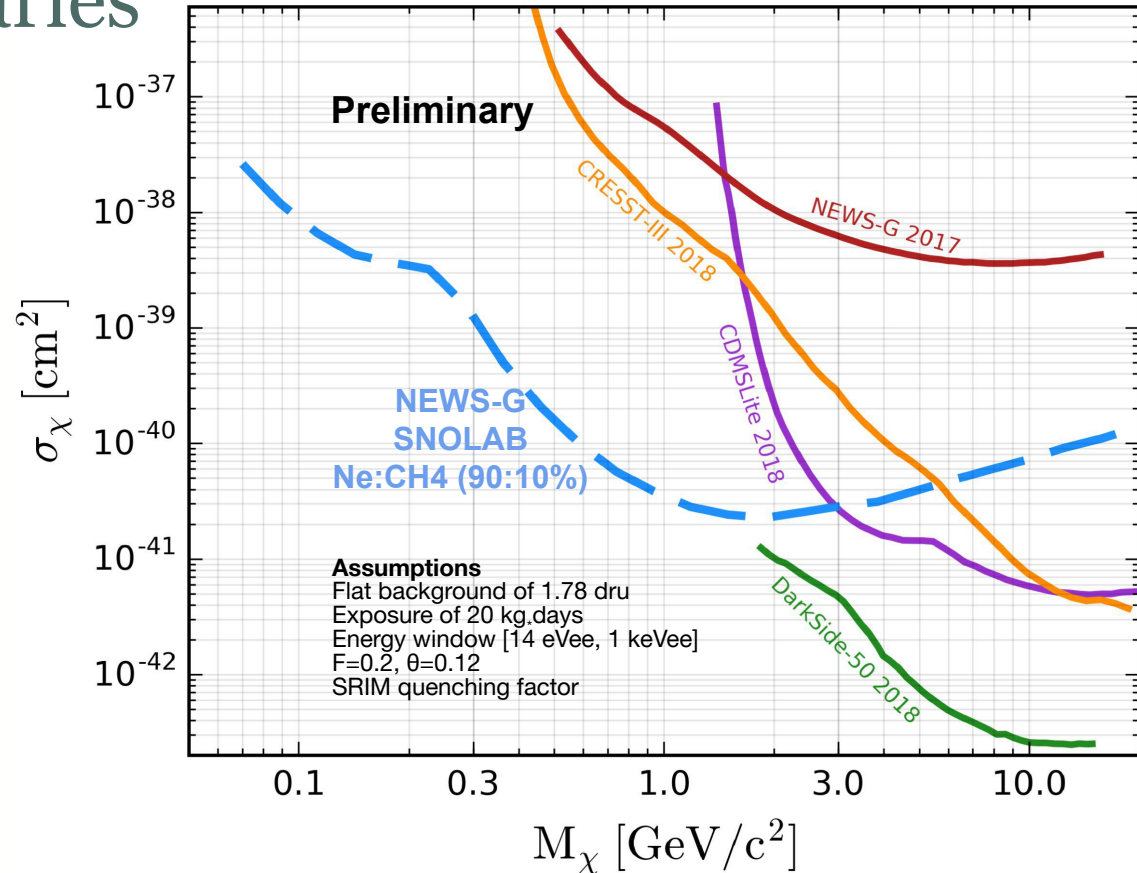
- Dedicated simulation framework
  - Combined GEANT4 and Garfield++ with FEM simulations (ANSYS)
  
- Study detector response
  - 2-channel ACHINOS
  - $^{37}\text{Ar}$  calibration
  - Fiducialisation



# Pushing the Boundaries

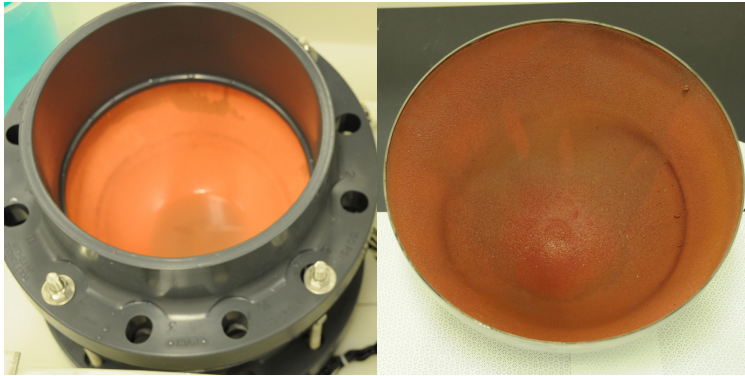
To increase low-mass sensitivity:

- Target mass
  - Larger detector
- Background suppression
  - PID and Fiducialisation
    - Sensor R&D
    - Dedicated simulation
  - Purity of Materials
    - Electroplating
- Low mass target nuclei
  - e.g. H from CH<sub>4</sub>



# ECUME - Electroformed CUprum Manufacturing Experiment

- **Underground electroformed  $\varnothing 140$  cm sphere**
  - **Minimised cosmogenic activation** - Electroformed in SNOLAB
  - **No machining or welding** - grow sphere directly
- Based on what was achieved for current NEWS-G sphere
  - 0.036 mm/day  $\rightarrow$   **$\sim 1$  mm/month**



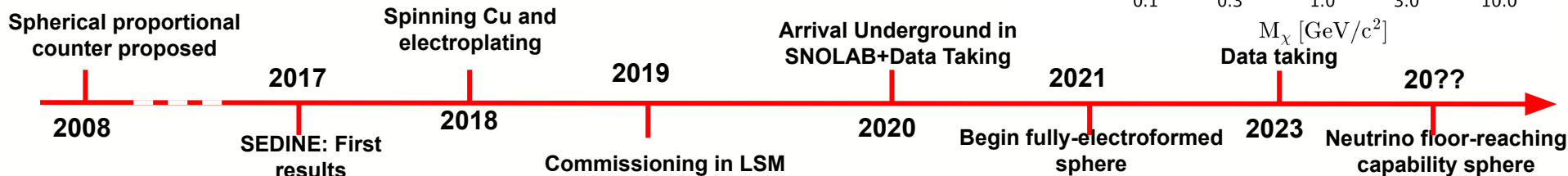
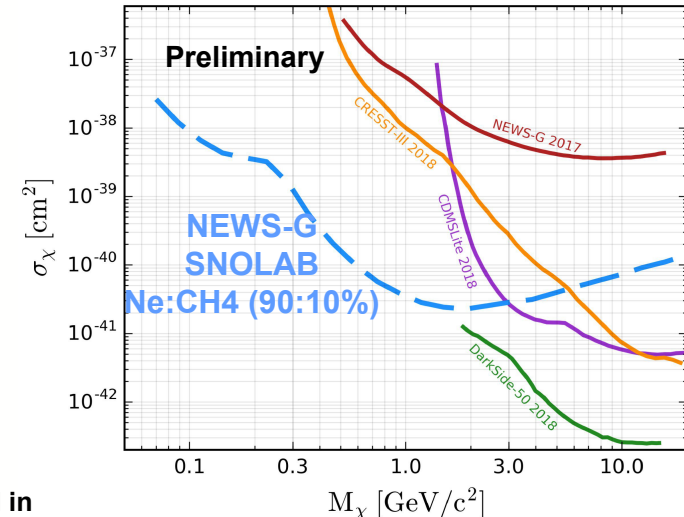
Scale hemi-spherical model (PNNL) used for previous electroplating of detector

## Current Status:

- R&D bath for prototype at PNNL - underway
- $\varnothing 30$  cm prototype will then be produced
- Full-scale scheduled for late 2021

# Summary and Outlook

- NEWS-G is searching for DM in the 0.1-10 GeV mass range
  - First competitive results with gaseous detector in DM search
- Next generation NEWS-G detector currently underground in SNOLAB
  - Larger detector and target mass
  - Improved procedures, material and shielding
- Active R&D effort: electroforming copper sphere, multi-anode sensors, multi-channel read-out, high-resistivity electrodes, high/low pressure operation...
- Exciting physics opportunities in near future!



# Additional Material