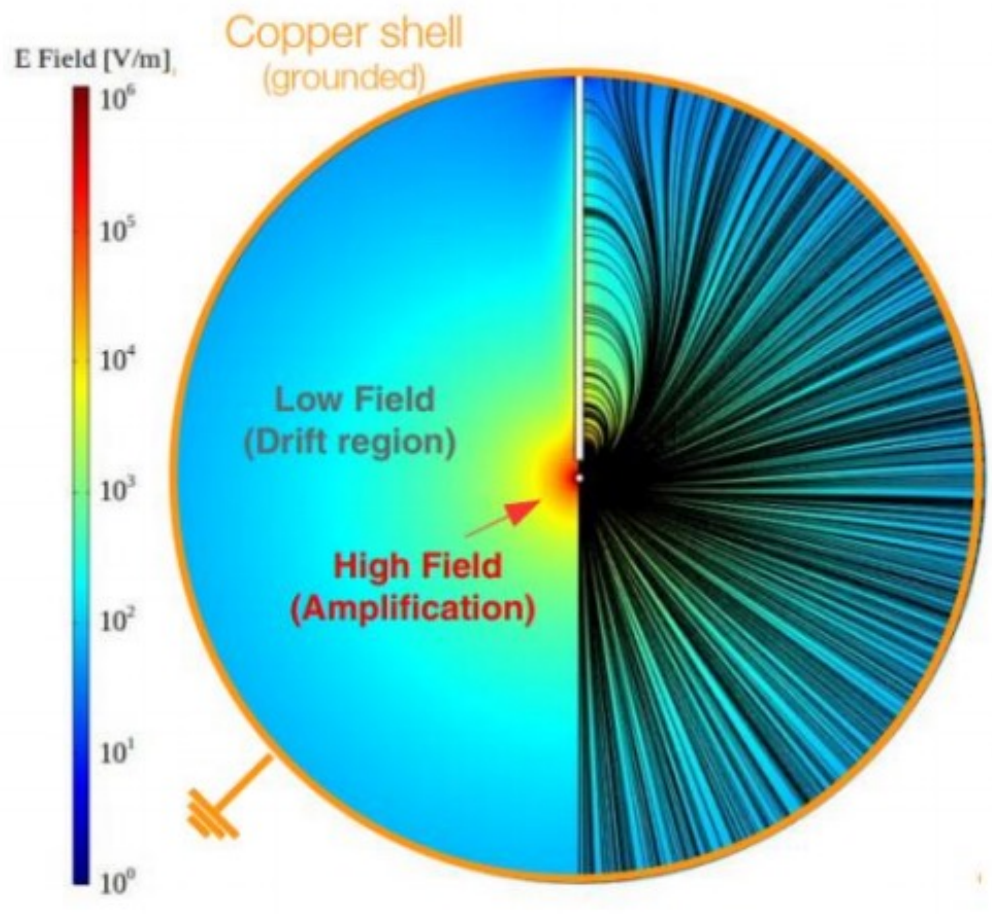
Status and Future of NEWS-G

Guillaume Giroux, Queen’s University

SNOLAB Future Project Workshop 2021

May 10 – 13, 2021

NEWS-G Spherical Proportional Counter



Sensitivity to single electrons

Low energy thresholds of 10 - 40 eVee

High amplification gain arising from $E(r) \propto \frac{1}{r^2}$

Low intrinsic capacitance (independent on the size of the sphere)

Easily scalable

$$C = \frac{4\pi\epsilon}{\left(\frac{1}{r_{sensor}} + \frac{1}{r_{vessel}}\right)} \approx 4\pi\epsilon r_{sensor} \approx 0.35\,\mathrm{pF}$$

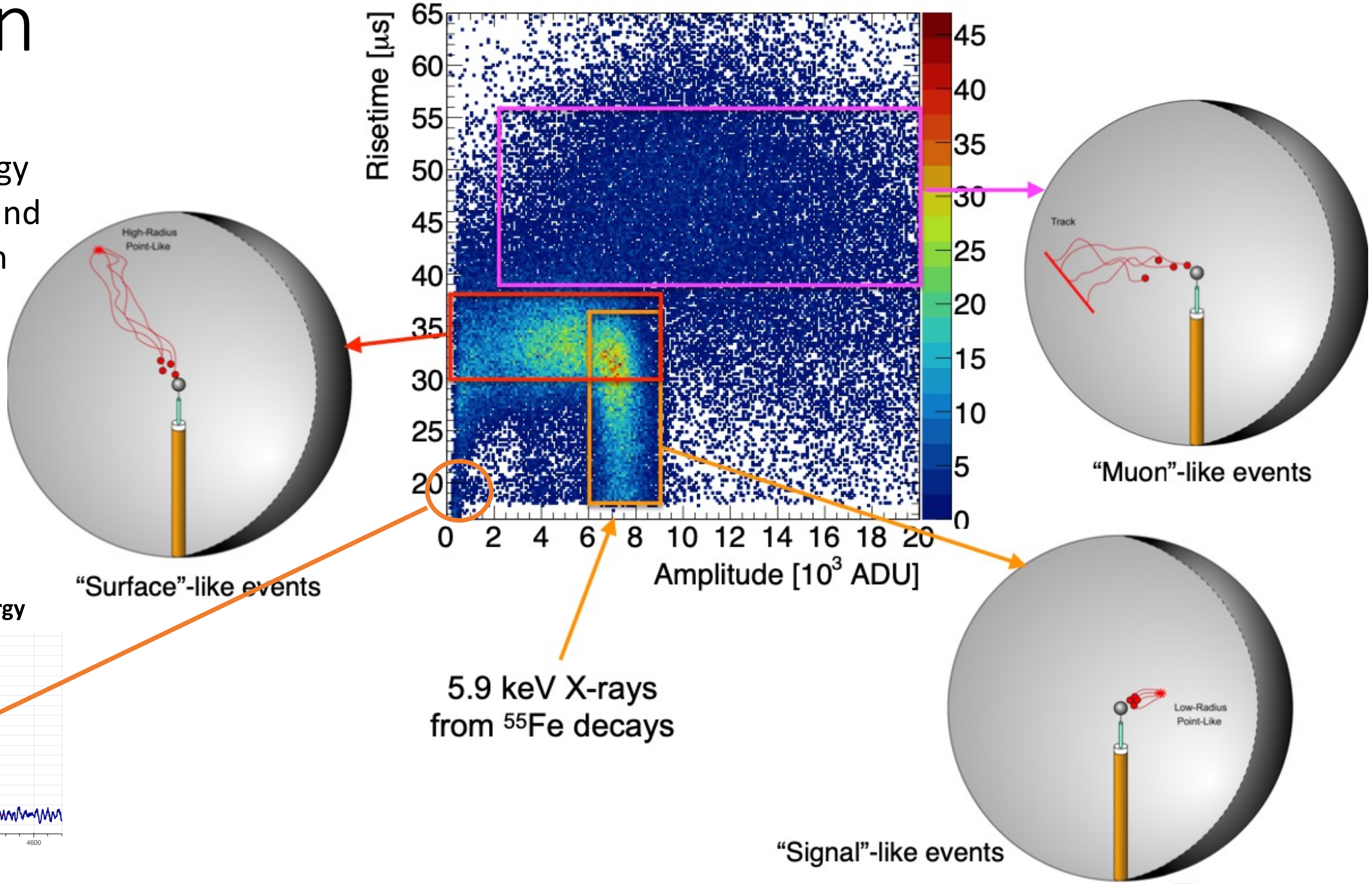
Pulse shape discrimination

The rise time of pulses allows for a statistical discrimination against sub-keV surface events

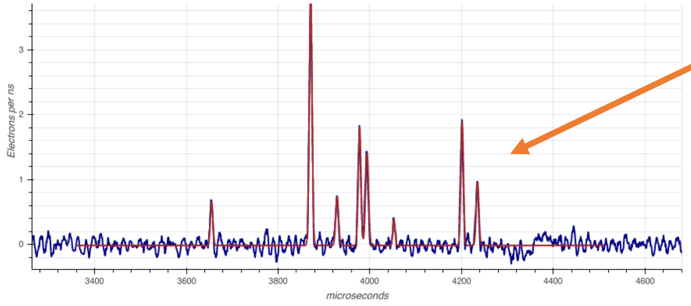
Light Targets (H,He,Ne)

Pulse Shape Discrimination

Risetime of pulses provide information on structure of energy deposition (point like v.s. tracks) and distance of point like deposition from anode (diffusion)



Counting the electrons at very low energy



Queen's University Kingston - G Gerbier, G Giroux, R Martin, S Crawford, M Vidal, G Savvidis, A Brossard, F Vazquez de Sola, K Dering, V Millious, J McDonald, M Van Ness, M Chapellier, P Gros, JM Coquillat, JF Caron, L Balogh
- Copper vessel and gas set-up specifications, calibration, project management
- Gas characterization, laser calibration on smaller scale prototypes
- Simulations/Data analysis

IRFU (Institut de Recherches sur les Lois fondamentales de l'Univers)/**CEA Saclay - I Giomataris**, M Gros, JP Mols
- Sensor/rod (low activity, optimization with 2 electrodes)
- Electronics (low noise preamps, digitization, stream mode)
- DAQ/soft

Aristotle University of Thessaloníki - I Savvidis, A Leisos, S Tzamarias
- Simulations, neutron calibration
- Studies on sensor

LPSC/LSM Laboratoire de Physique Subatomique et Cosmologie, Laboratoire Souterrain de Modane) **Grenoble** - D Santos, M Zampaolo, A DastgheibiFard JF Muraz, O Guillaudin
- Quenching factor measurements at low energy with ion beams
- Low activity archaeological lead
- Coordination for lead/PE shielding and copper sphere

Pacific Northwest National Laboratory - E Hoppe, R Bunker
- Low activity measurements, copper electro-forming

RMCC Kingston - D Kelly, E Corcoran, L Kwon
- ^{37}Ar source production, sample analysis

SNOLAB Sudbury - P Gorel, S Langrock
- Calibration system/slow control

University of Birmingham - K Nikolopoulos, P Knights, I Katsioulas, R Ward
- Simulations, analysis, R&D

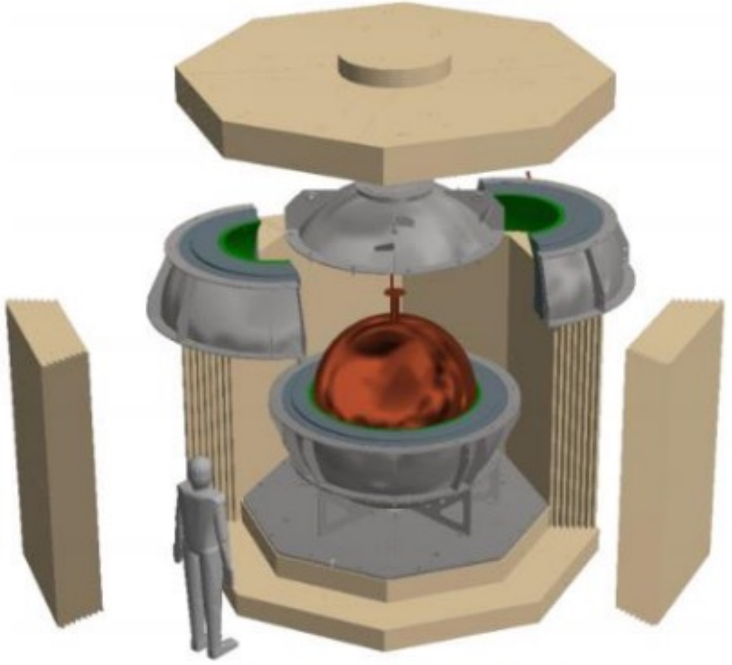
University of Alberta - MC Piro, D Durnford, Y Deng, P O'Brien, C Garrah
- Gas purification, data analysis, simulation

Associated labs: TRIUMF - F Retiere

Subatech, Nantes – P. Lautridou, F. Vazquez de Sola

NEWS-G at SNOLAB

140 cm diameter low activity copper (C10100) SPC
7 - 25 µBq/kg ^{232}Th
1 - 5 µBq/kg ^{238}U
Electropolishing and electroplating



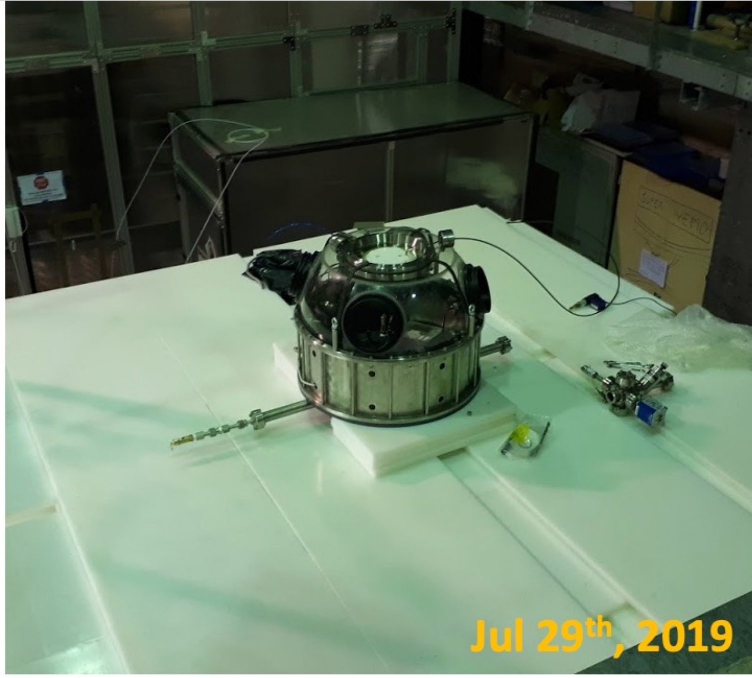
Compact Shielding (35 t)
40 cm borated PE
22 cm low activity Pb (3 cm archeological Pb)
SS enveloppe flushed with pure N (radon mitigation)

NEWS-G at LSM

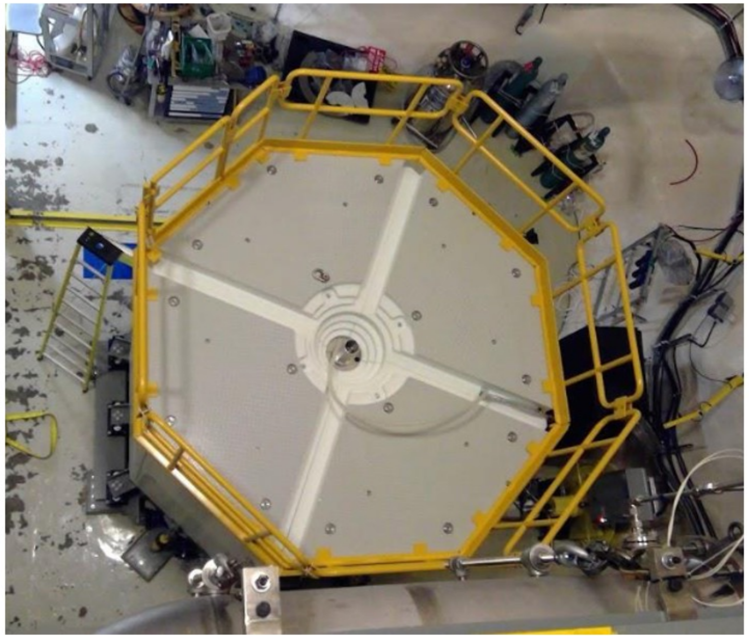
6 days physics run with pure CH_4 at 135 mbar

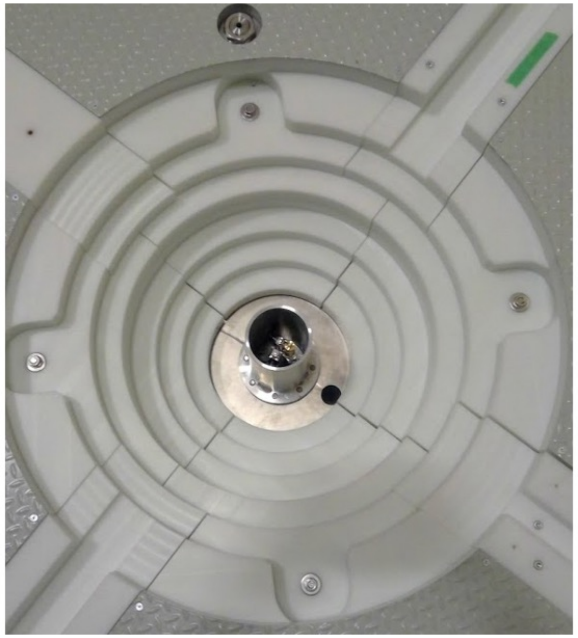
Results anticipated this summer!

SD and SI on Hydrogen target



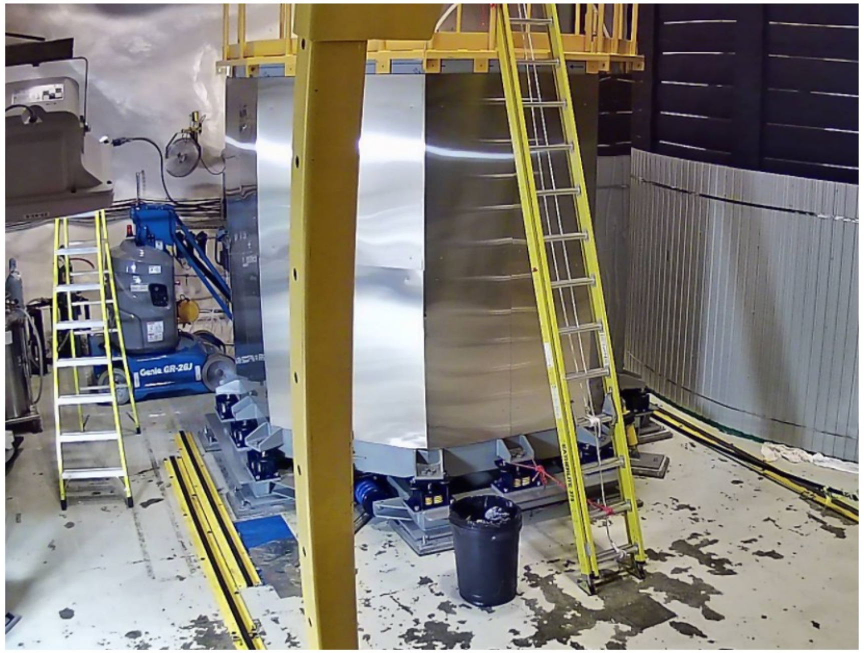
NEWS-G at SNOLAB



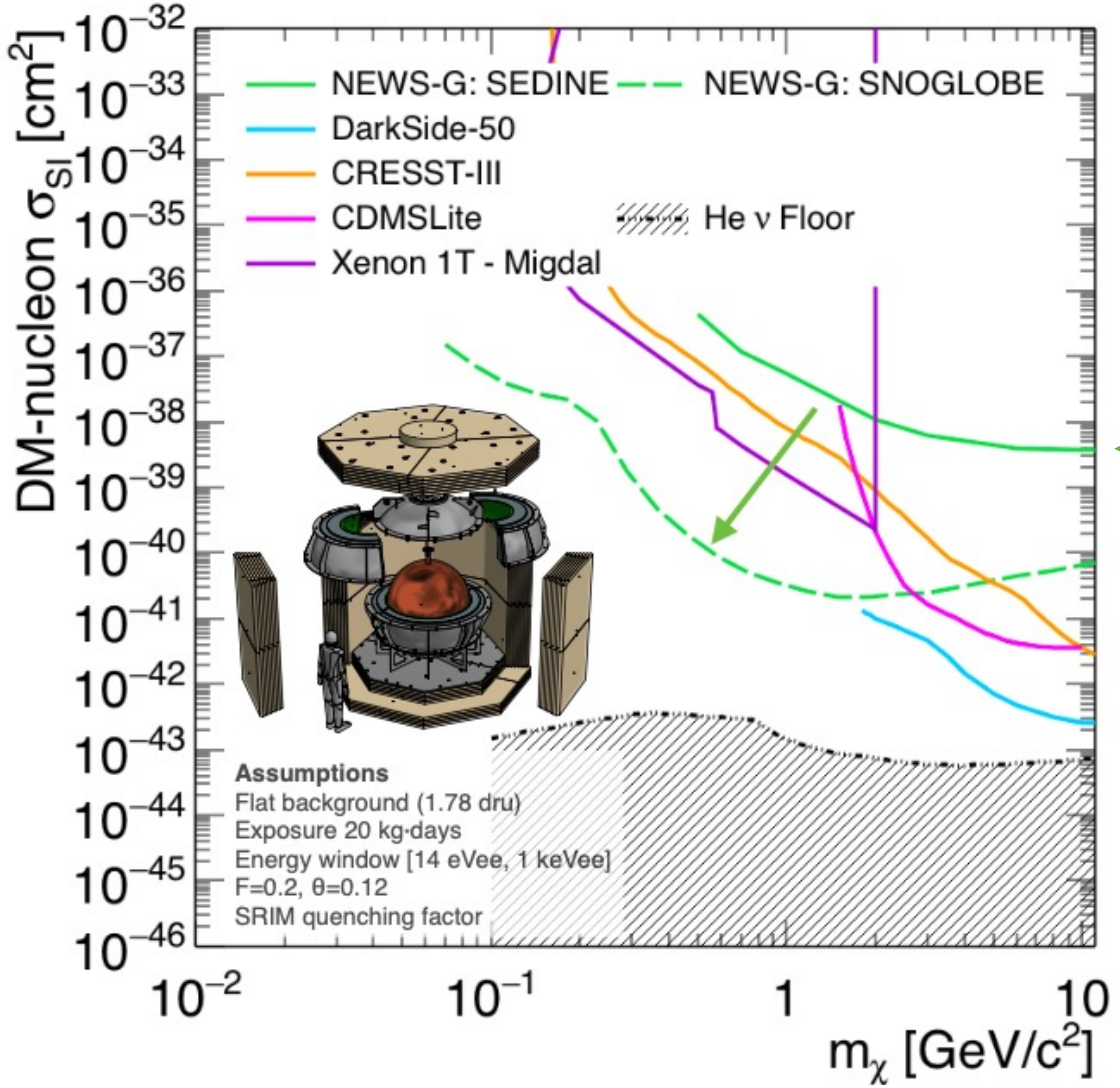


- A lot of progress on the installation during Fall 2020 thanks to contractor team provided by SNOLAB

- Delayed by Covid restrictions, but only a few weeks needed for commissioning and start data taking with Ne/CH_4

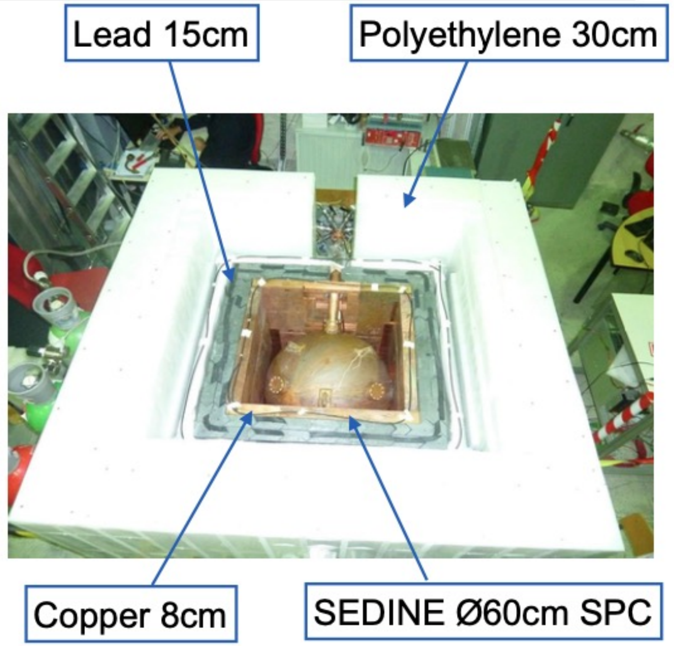


NEWS-G at SNOLAB: Projected Sensitivity



SEDINE @ LSM (2017)

$Ne+CH_4$(0.7%) 3.1 bar, 9.7 kg-days



Q. Arnaud, *et al.*, First results from the news-g direct dark matter search experiment at the LSM, Astropart. Phys. **97** (2018) 54–62.

Future of NEWS-G

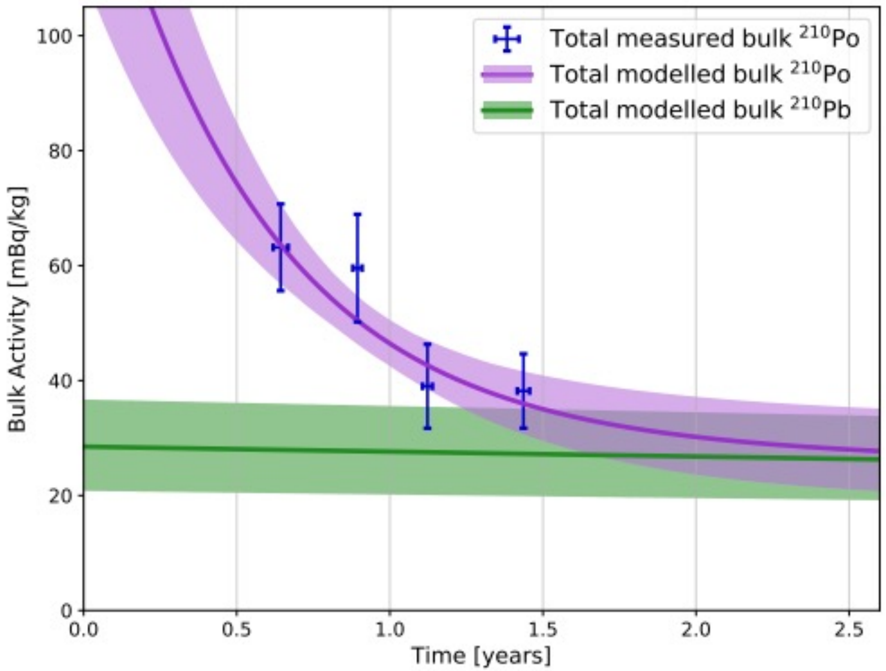
Upgrades to NEWS-G at SNOLAB, and planning for the next-generation NEWS-G experiment:

- Addressing the copper backgrounds
- Increasing the exposure
- Understanding the response at very low energy

Copper Backgrounds

- Surface ^{210}Pb can be mitigated with surface etching
- Measurements of alpha particles with XIA surface alpha counter can be used to assess ^{210}Pb in the bulk
- For C10100 copper (4.5N) we found more (~30 mBq/kg) ^{210}Pb in the bulk than expected from U/Th measurements
- ^{210}Pb in the copper bulk will be the leading source of background in NEWS-G at SNOLAB (^{210}Bi bremsstrahlung)

XIA UltraLo-1800 (XMASS Collaboration)



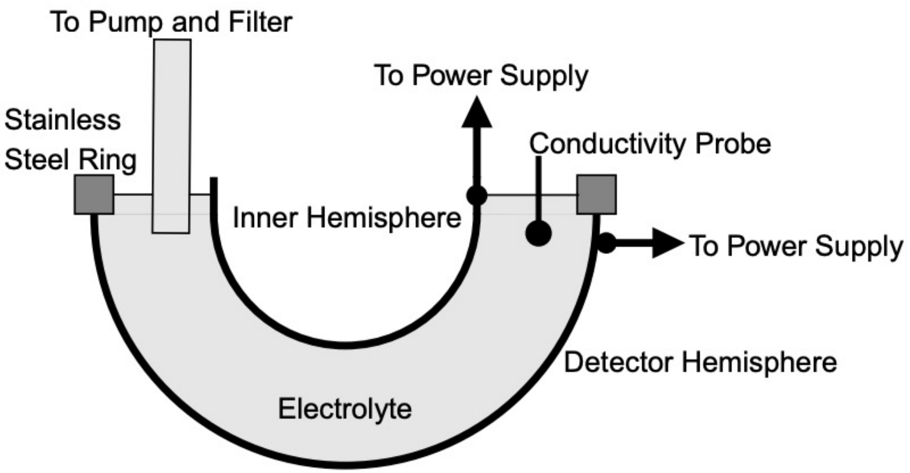
1.5 dru

Figure 3: Measurements of the α particles from the decay of ^{210}Po in a sample of C10100 copper used in the production of the NEWS-G detector. Time is measured from the estimated production date of the copper. The purple (green) line shows the fitted ^{210}Po (^{210}Pb) activity over time, with the bands showing the $\pm 1\sigma$ region.

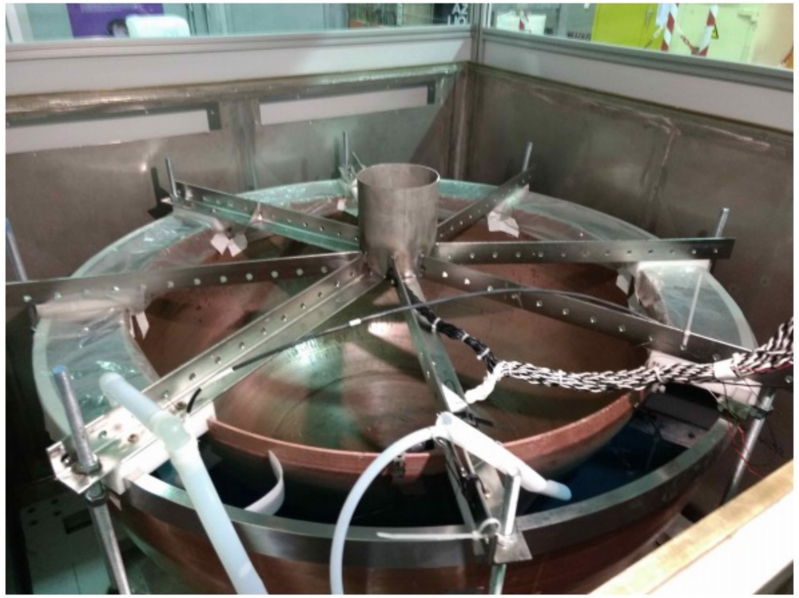
Nucl.Instrum.Meth.A 988 (2021) 164844

Copper Electroplating

To mitigate bulk ^{210}Pb backgrounds, the 140-cm NEWS-G SPC hemispheres were electroplated with 0.5 mm pure copper at LSM

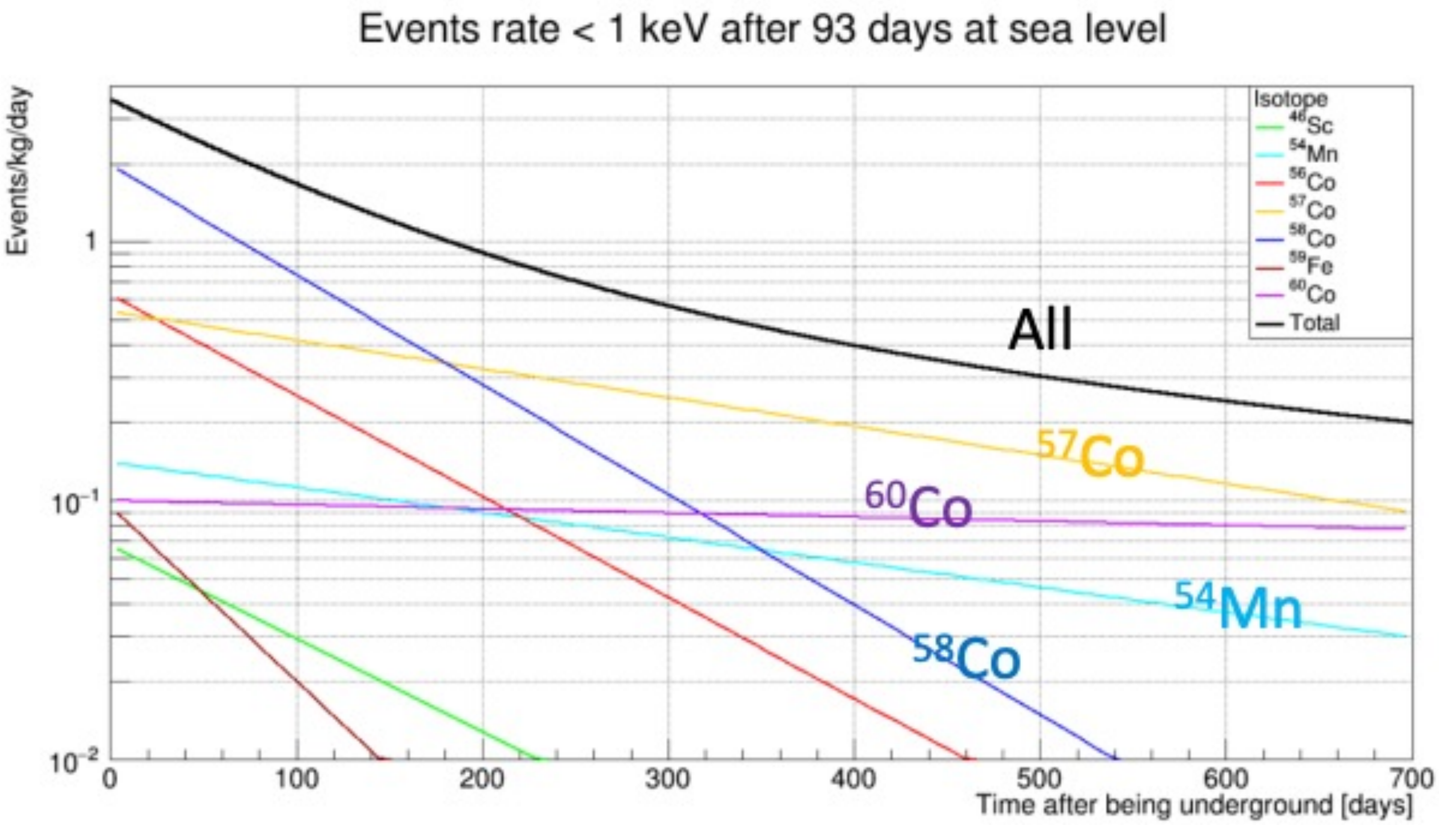


Nucl.Instrum.Meth.A 988 (2021) 164844



Copper Backgrounds

- Cosmogenic activation of copper during manufacturing (machining, spinning, e-beam welding, transport)

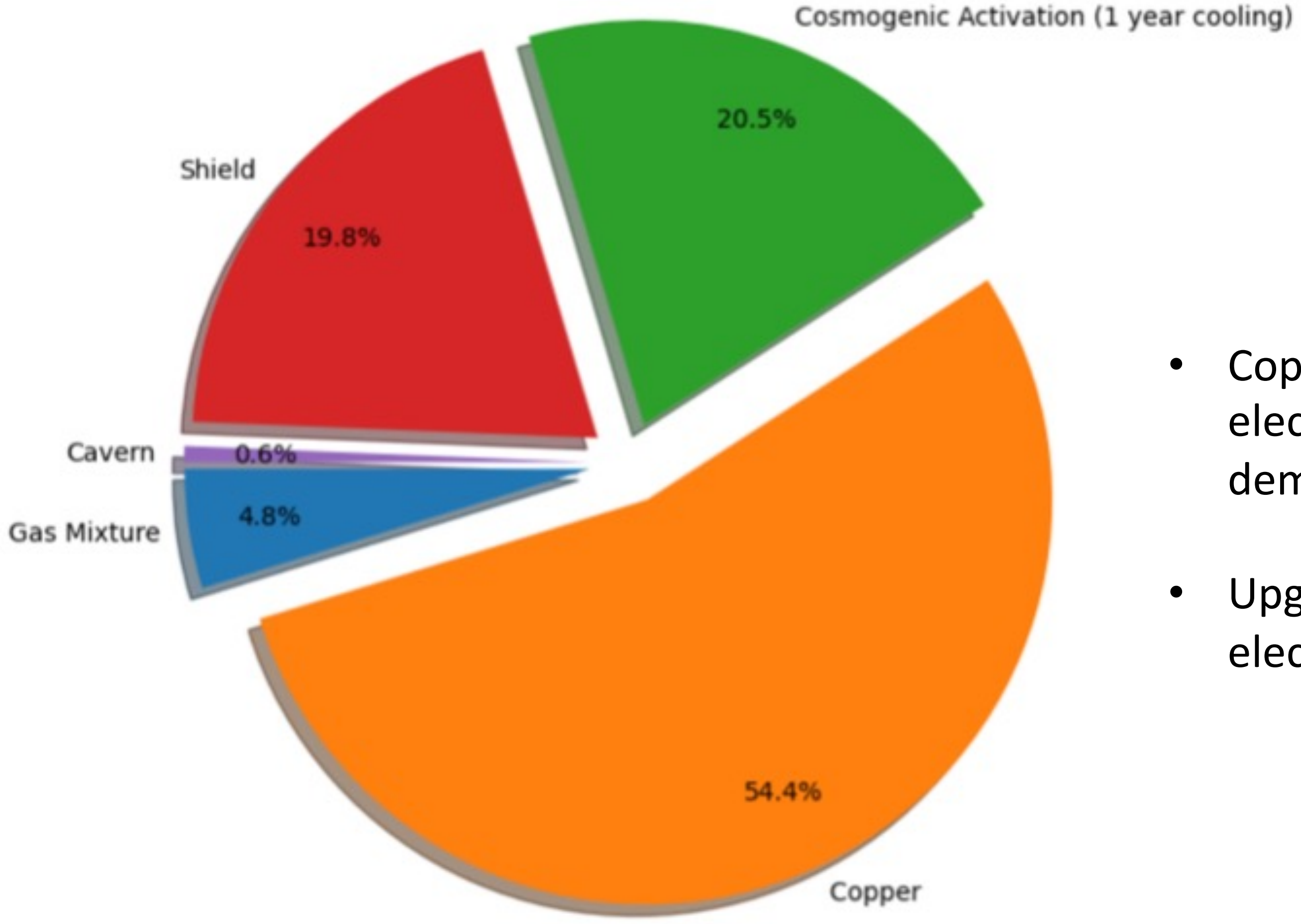


4 dru at t = 0

0.4 dru at t = 1 year

Alexis Brossard (Queen's)

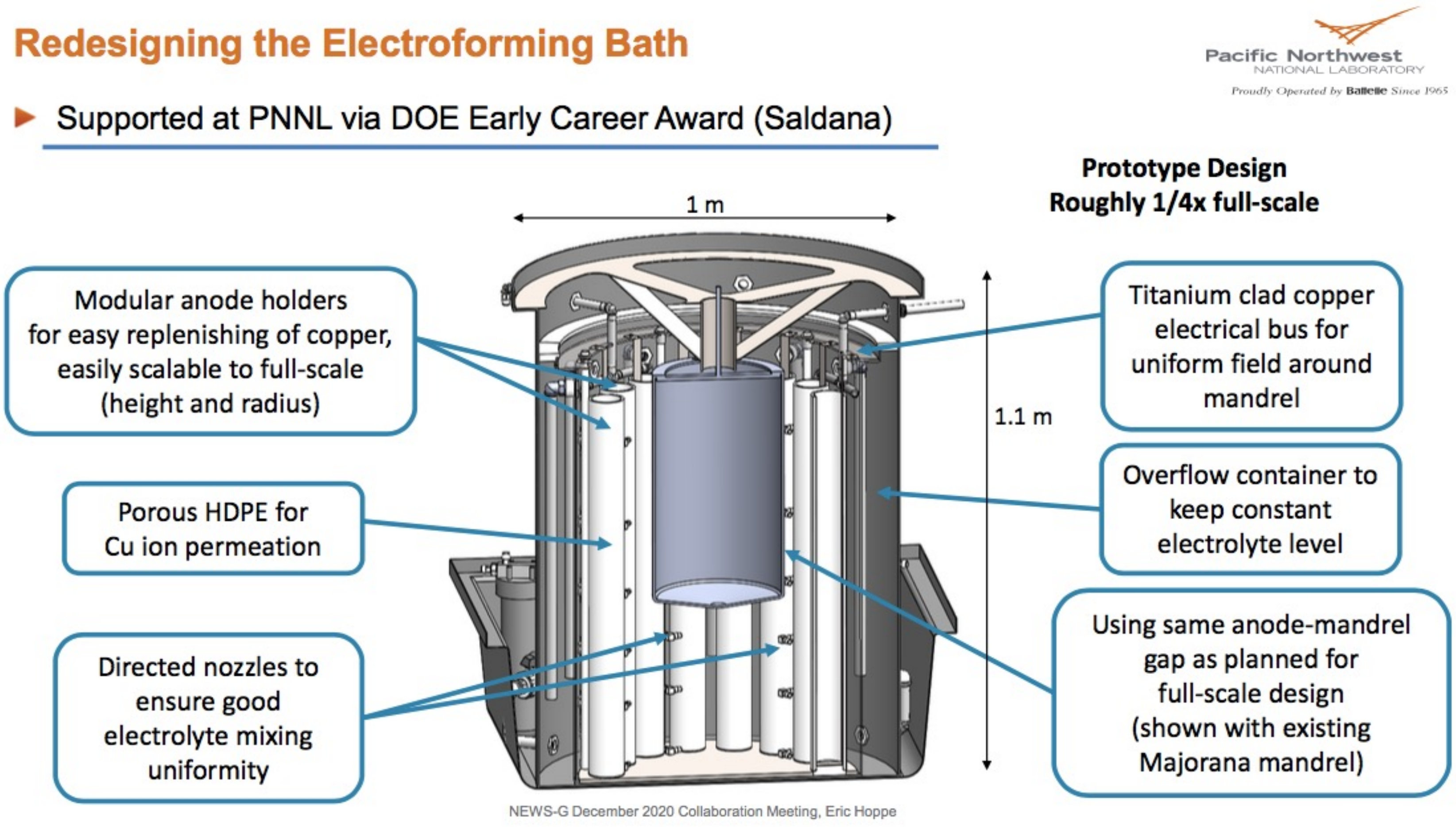
Copper Backgrounds



- Copper backgrounds can be eliminated with copper electroforming in underground lab (as demonstrated by PNNL)
- Upgrade to NEWS-G at SNOLAB: 140-cm fully electroformed copper SPC at the ECuME facility

Electroformed copper: ECuME at SNOLAB

Partnership between Queen's, PNNL and SNOLAB

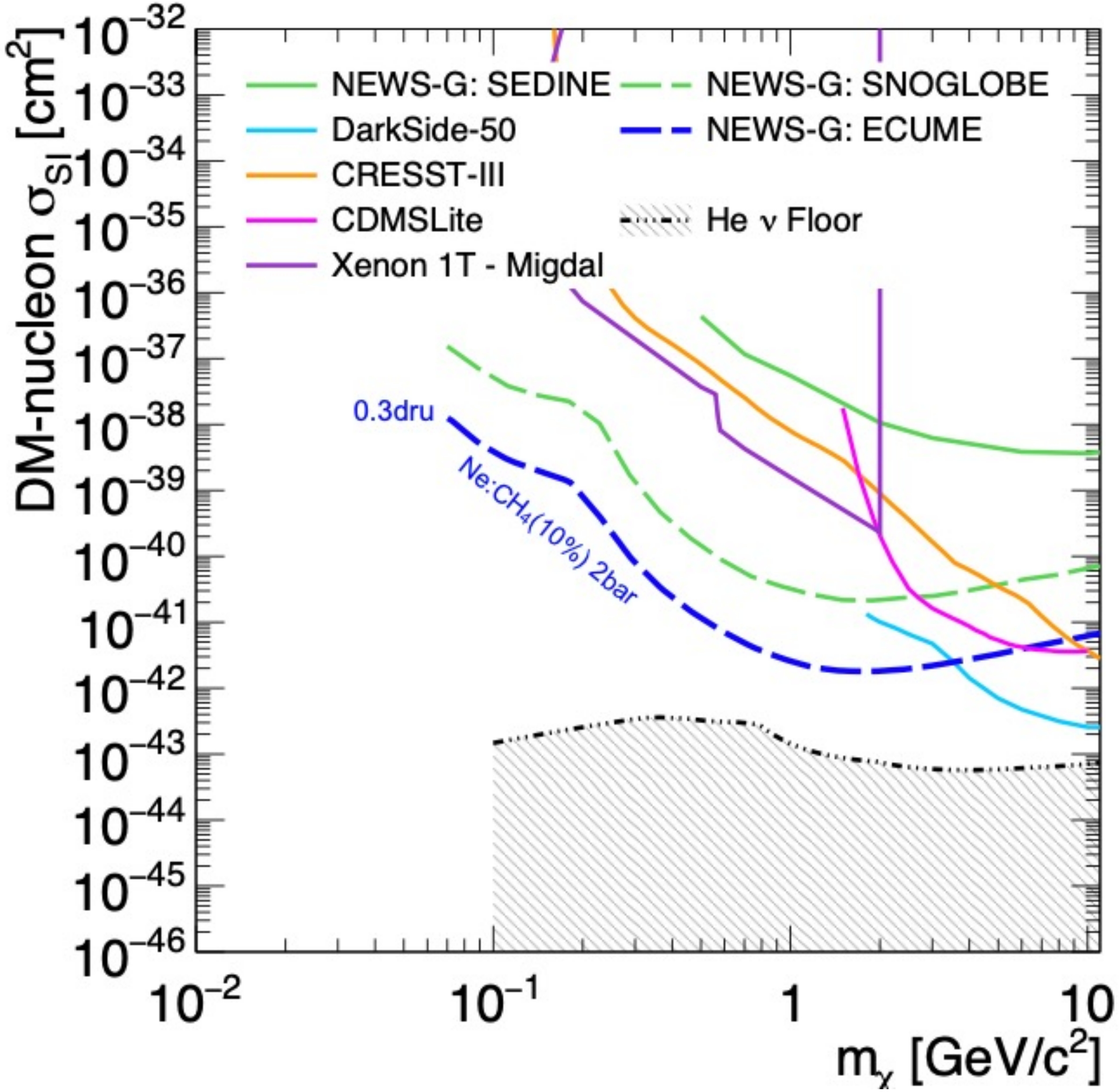


PNNL 200 L bath:
30 cm SPC prototype late 2021

ECuME 1000 L bath:
140 cm SPC late 2022

*See Shaun Hall talk on Wednesday

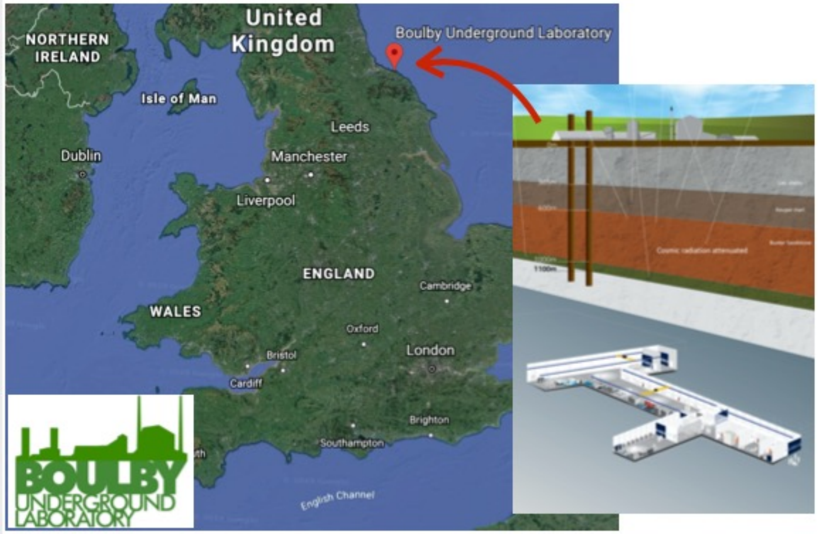
Electroformed Copper: Sensitivity Projections

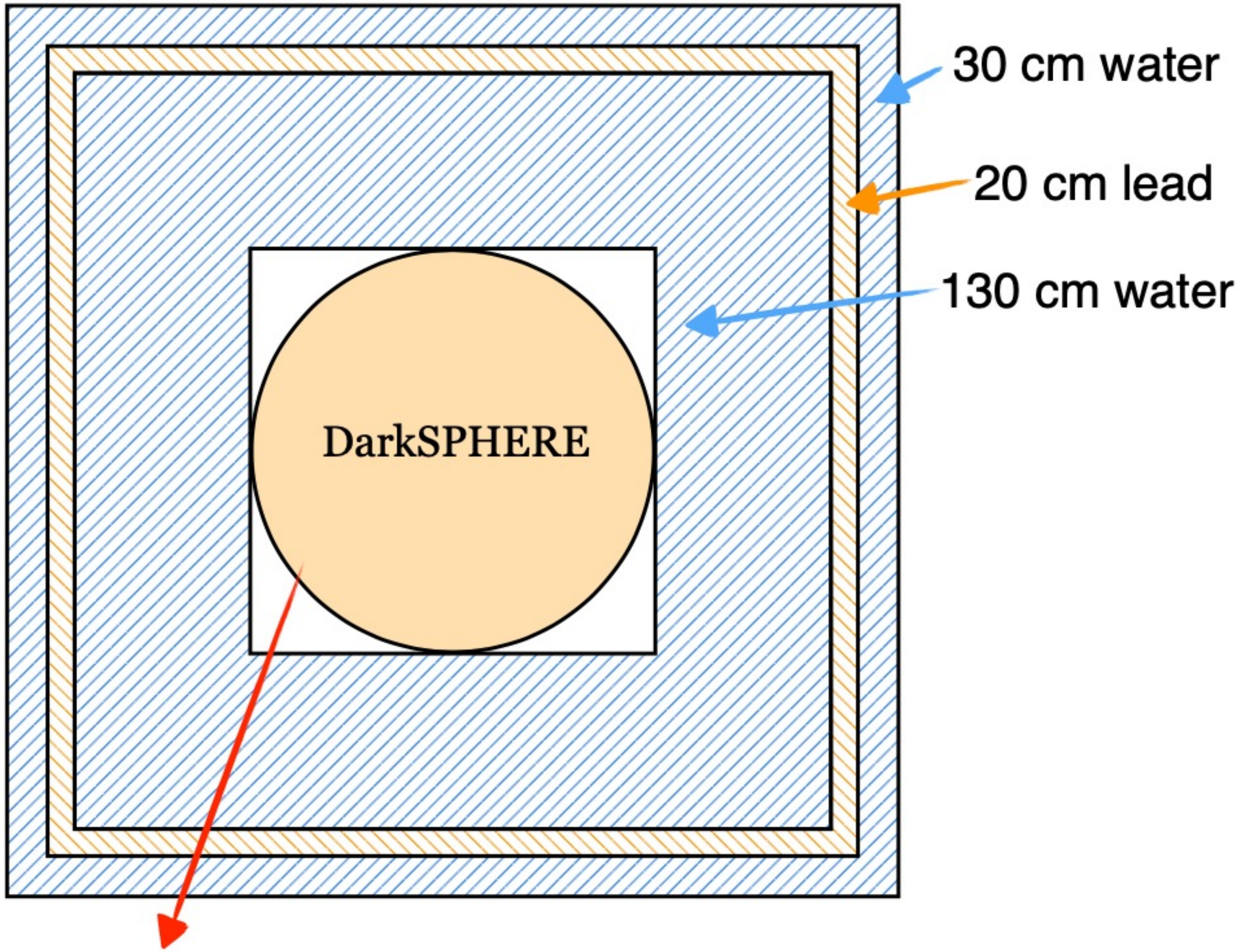


Increasing the Exposure: DarkSPHERE

Configuration	Photons [dru]	Neutrons [dru]
Water (2 m)	8	0.002
Water (3.5 m)	0.002	<0.002
Water-lead	0.005	0.002

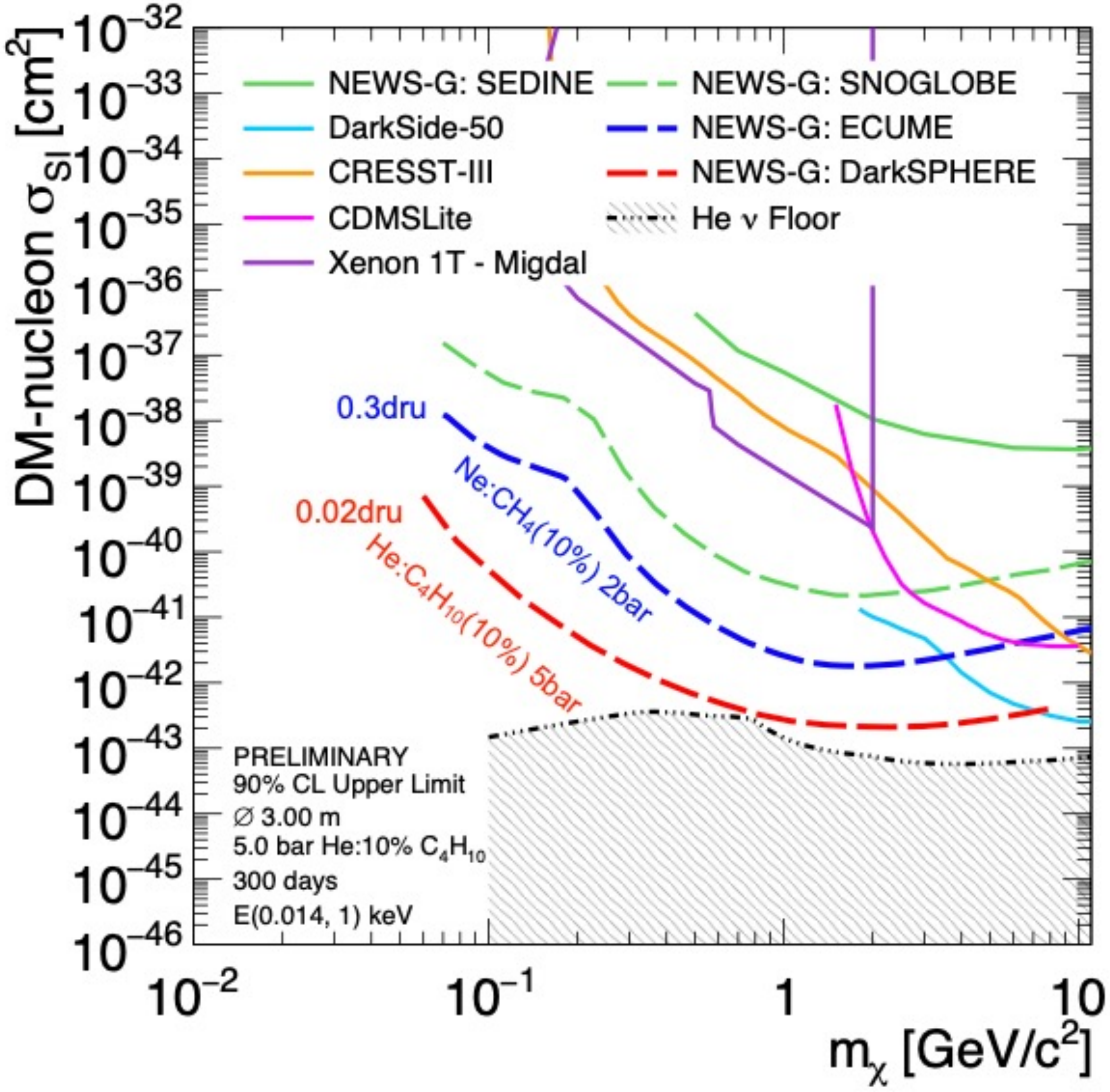
Assuming installation at Boulby





Operation with 5 bar He:C_4H_{10} (90%:10%) (27 kg)

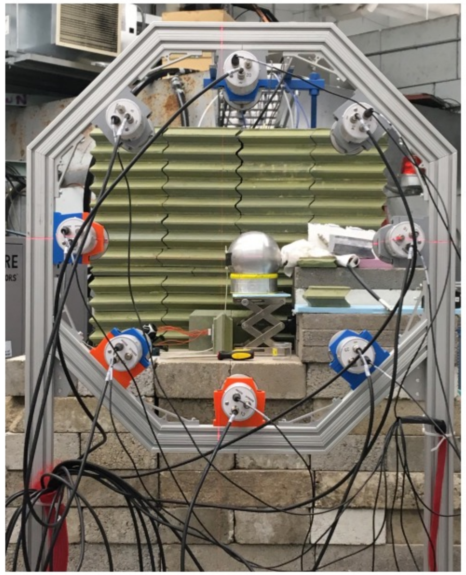
DarkSPHERE: Sensitivity Projections



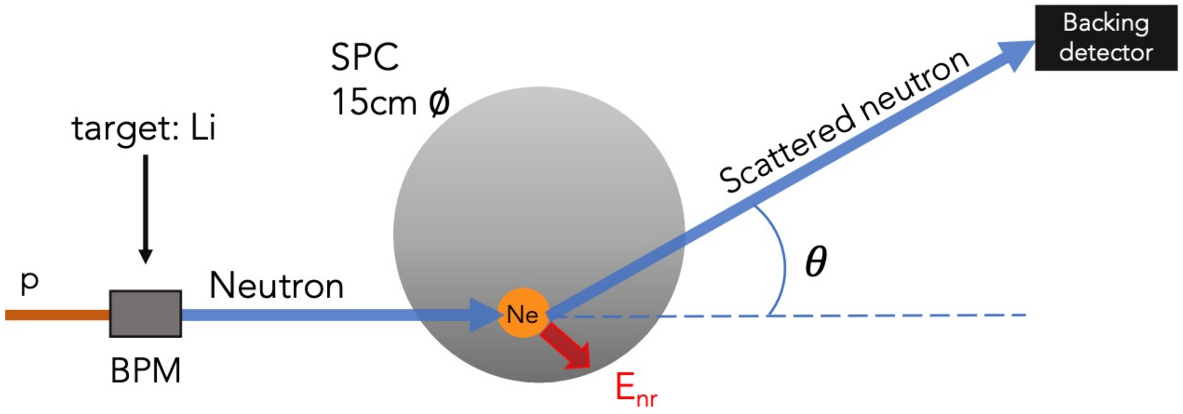
Understanding the Response at Very low Energy: Quenching Factor

Measurement of Quenching Factor (Nuclear Recoil Ionization Yield) in Neon at TUNL

- QF measurements with neutron beam at TUNL E_n = 545 ± 20 keV
- Gas mixture: Neon + CH_4 (97:3) @ 2 bar
- 8 energy points: ~ 0.3 to 7 keV_{nr}
- $QF(E_{nr}) = E_{ee}/E_{nr}$



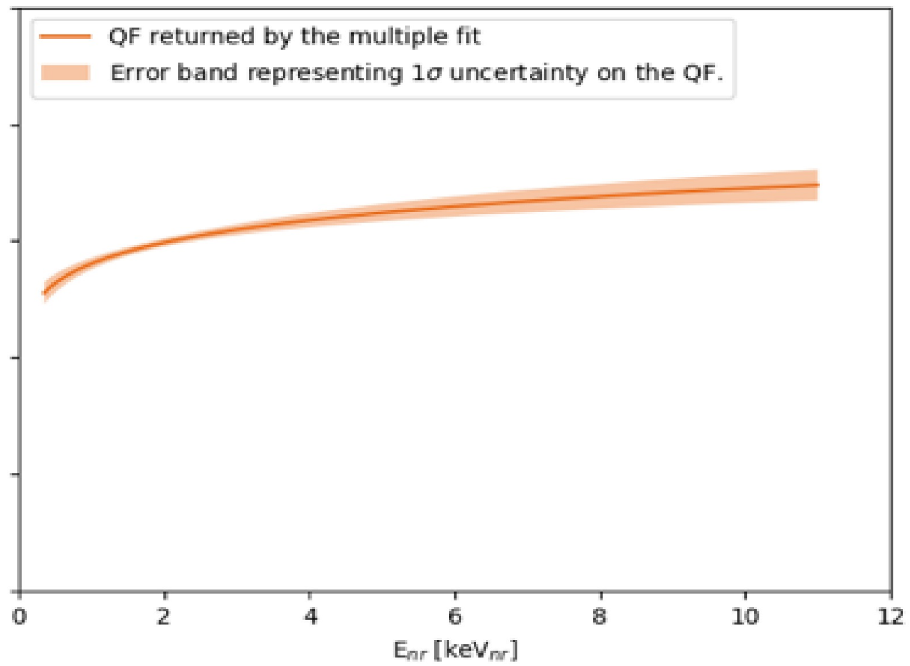
Run	E_{nr} [keV_{nr}]	θ [^{o}]
8	6.8	29.02
7	2.93	18.84
14	2.02	15.63
9	1.7	14.33
10	1.3	12.48
14	1.03	11.13
11	0.74	9.4
14	0.34	6.33



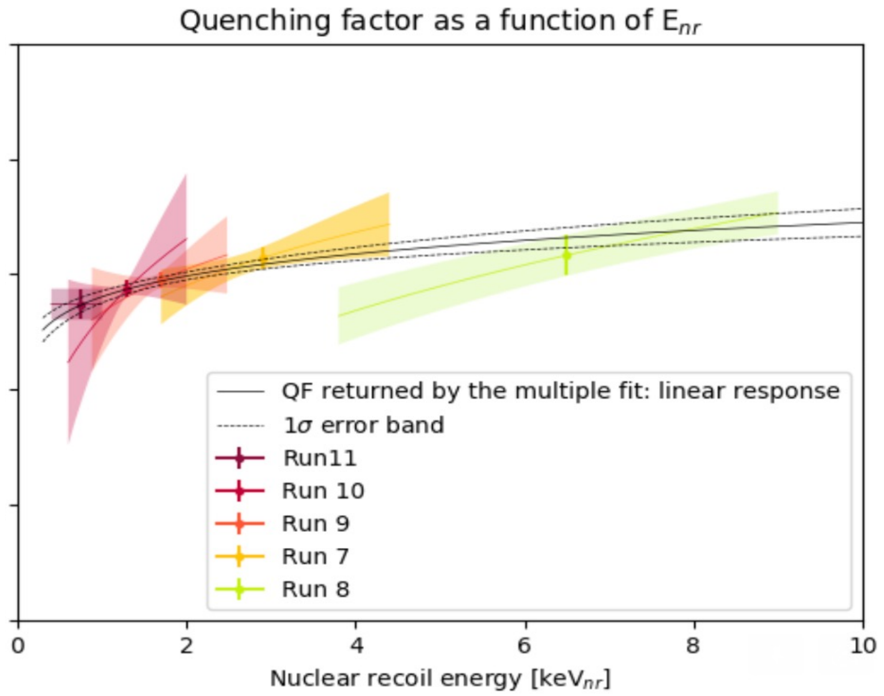
Quenching Factor

Neon quenching in Neon/CH4: Paper in final review stage!

Validation: individual fits



Joint Fit Final Results



Marie Vidal (Queen's)

Quenching Factor of Proton

Jean-François Caron (Queen's)

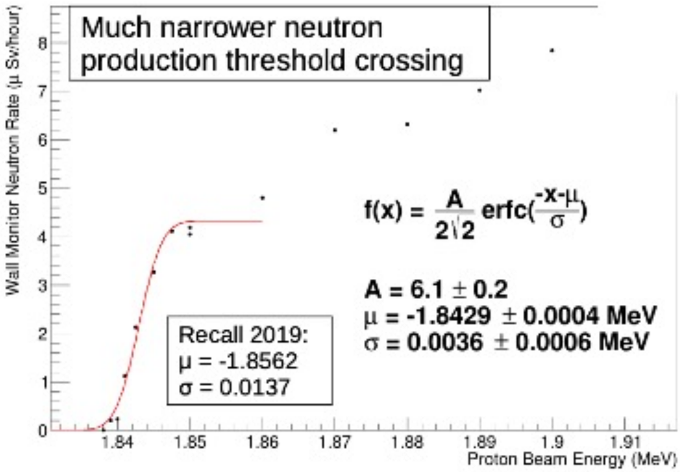
QF Measurements at Queen's (RMTL)

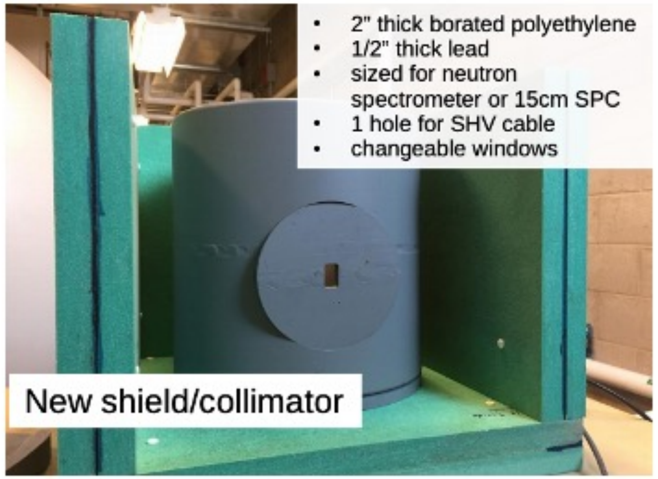
Goal:

- QF measurements with ~30 keV neutrons from $^{7}Li(p,n)^{7}Be$ production, for low energy recoils on Ne, He, H

Recent Progress:

- Narrower neutron threshold achieved thanks to thinner LiF target, removal of target water cooling, alignment
- Construction of a shielding for the SPC or nested neutron spectrometer
- Data taking with 15-cm SPC, custom made sensor and ^{55}Fe source holder
- Acquisition of HV power supply, neutron backing detector, preamp power supply





Current work:

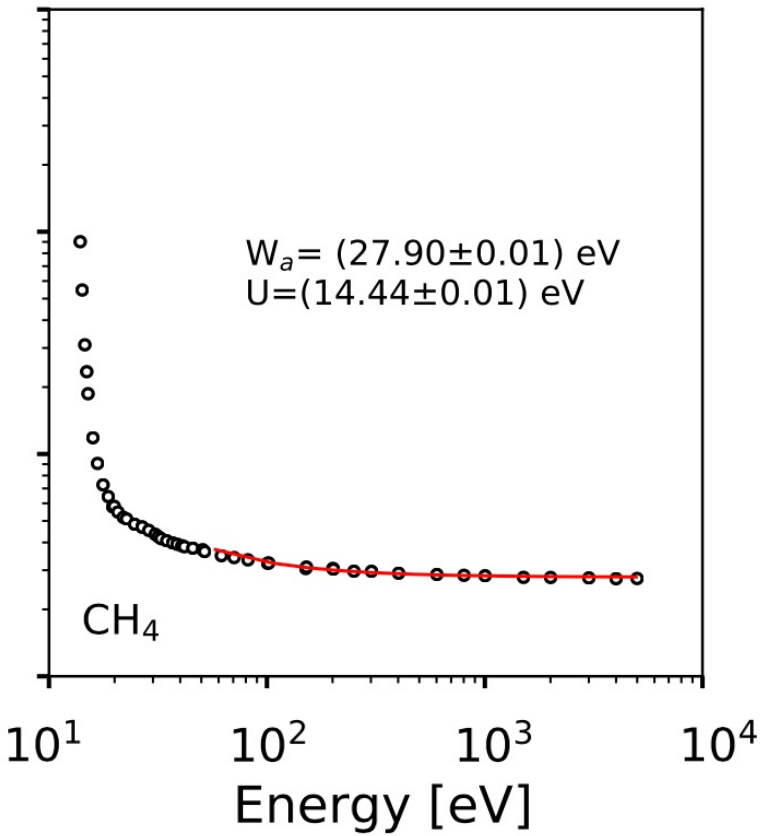
- Understanding the response of the neutron spectrometer
- Tuning up SPC operation and data analysis

Also: QF of proton and ions with COMIMAC ion source at Grenoble

Understanding the Response at Very Low Energy: W-Value

- W-Value: average energy to create an electron-ion pair
  - Different for electrons and ions (quenching factor)
  - Constant value at higher energy (~1 keV)
  - Depends on energy at low energy
    - The fraction of energy that goes into ionization v.s. excitation changes
    - Molecular dissociation

Electron W-Value

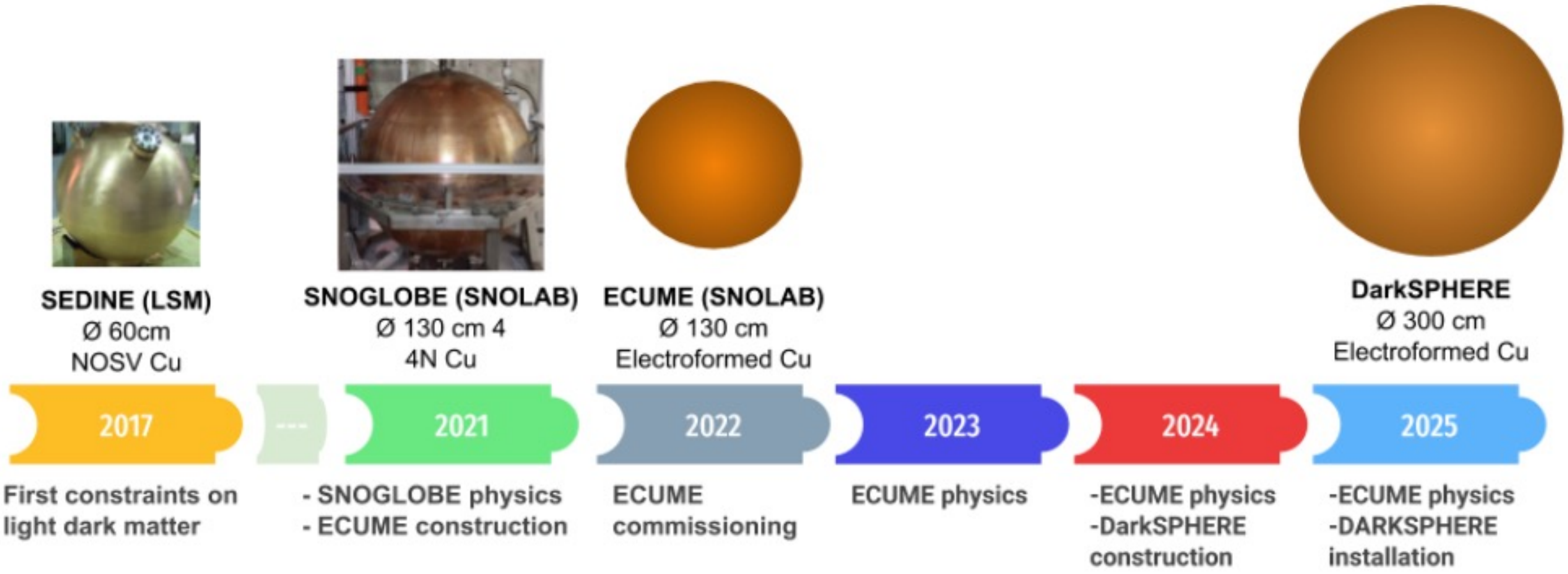


See recent discussion on W-Value and Quenching factor:

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

I. Katsioulas *et al.*, arXiv:2105.01414

NEWS-G Timeline



Thank You

Extra Slides

Milestones

Past Milestones:

Jul. 2019	Installation at LSM
Aug. 2019	Data taking start at LSM
Sep. 2019	Physics run with pure CH_4 at LSM
Oct. 2019	LSM Decommissioning
Nov. 2019	Shipping out of LSM
Dec. 2019	Receiving at SNOLAB
Jan. 2020	HQP Training and Pb Cleaning
Feb. 2020	Pb Shield Underground
Oct. 2020	Installation of Shield on Seismic Platform
Nov. 2020	Sphere Etching and Shield Completion

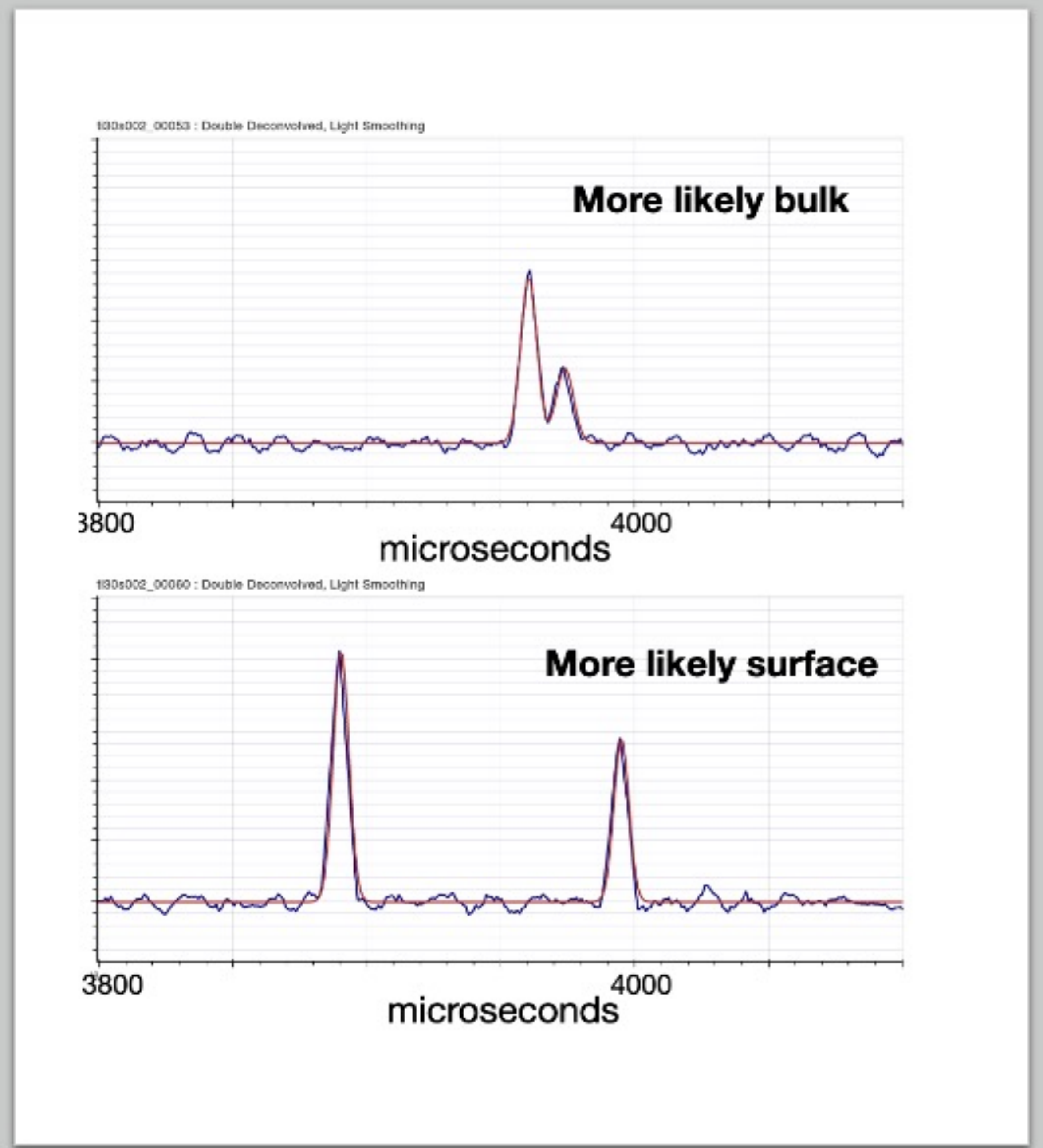
Future Milestones

Winter 2021	Completion of the Installation
Spring 2021	Commissioning and Data Taking

D. Durnford (Alberta)

Primary Electron Identification

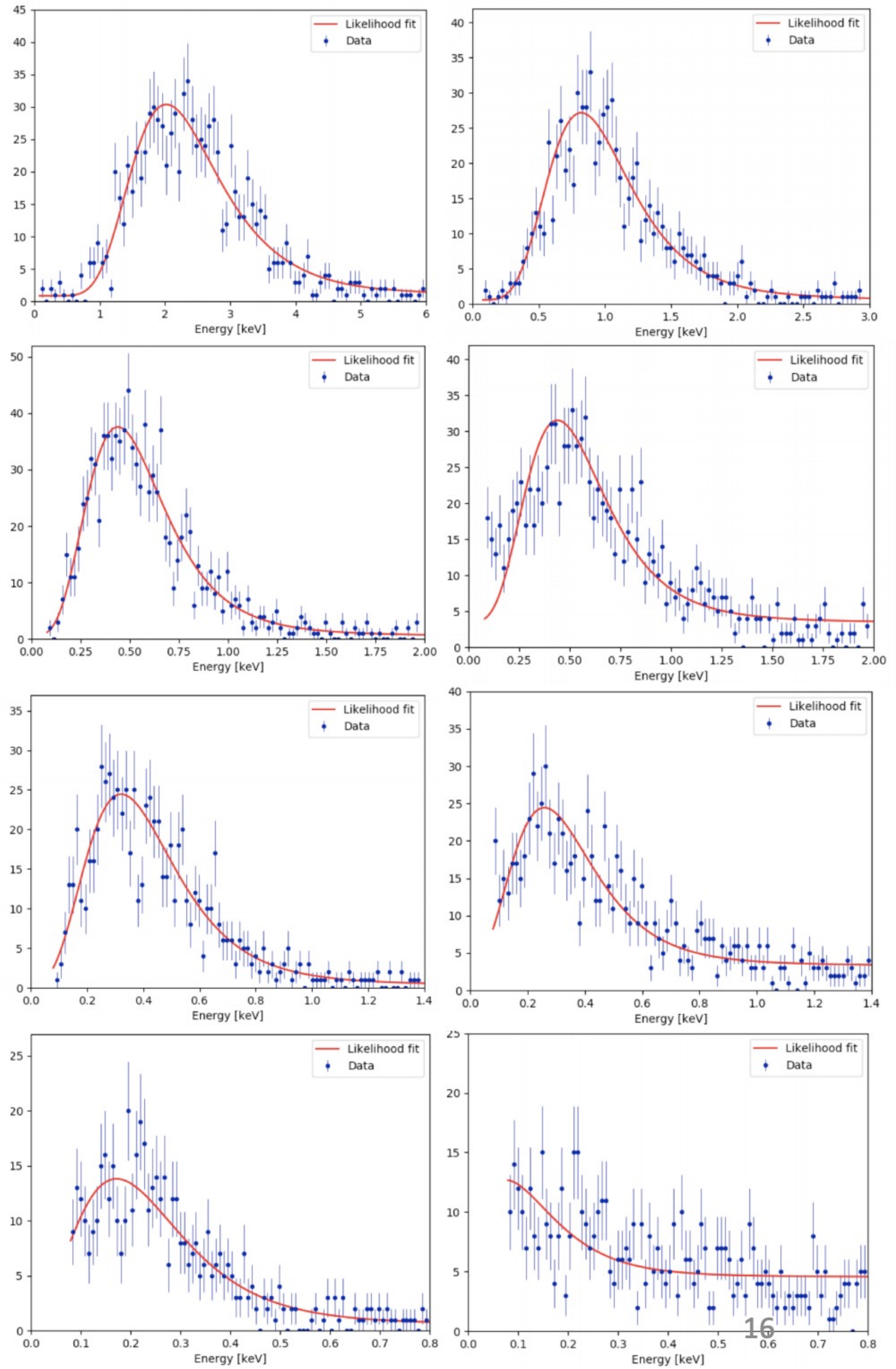
- We select only events with exactly two primary electrons. Reject single electron events (produced primarily by after-effects of high energy events), events with 3+ electrons (negligible creation by WIMPS under 1 GeV).
- Time separation between two primary electrons can be used to discriminate against surface events.



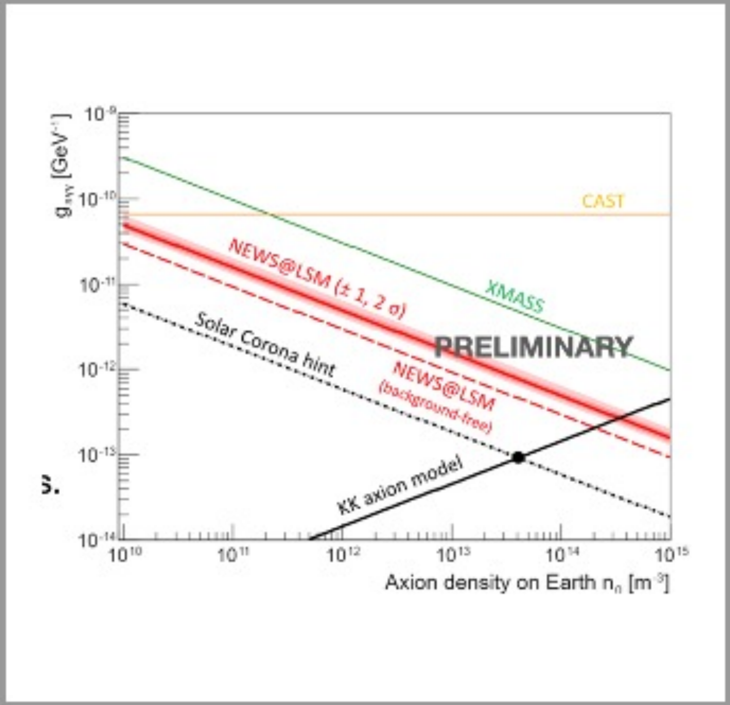
Quenching Factor

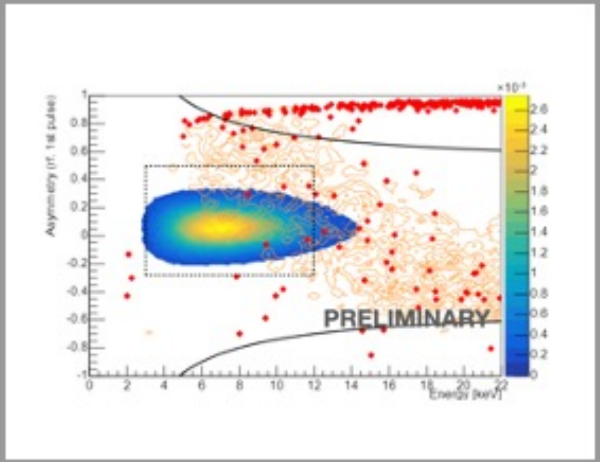
Measurement of Quenching Factor (Nuclear Recoil Ionization Yield) in Neon at TUNL

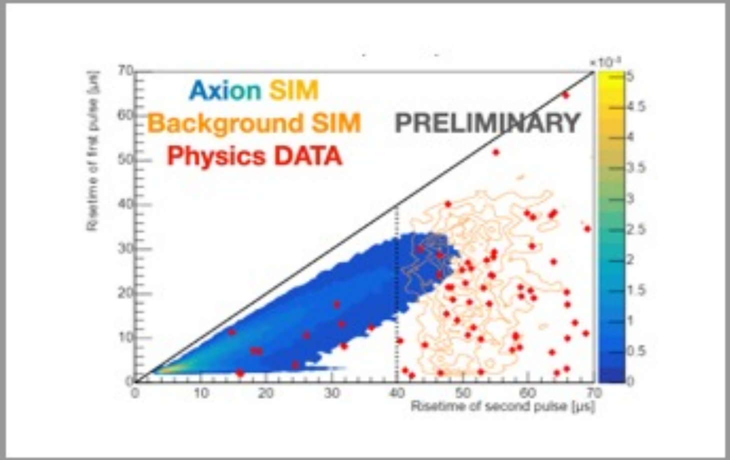
- joint/simultaneous unbinned likelihood fit
  - extract the parameters of the QF throughout the energy range covered.
- Modelling of the recoil events (signal):
  - Geometry of the experiment: scattering angle distribution
  - Neutron energy distribution
  - Response of the detector
  - Include quenching factor:
    - parametrization of the QF (αE_{nr}^{β}): free parameters in the fit
  - Fluctuation of the gain throughout the volume implemented.
  - efficiency reconstruction
- QF parameters are shared with all the runs.
- The results of the joint fit to data is shown in red
  - the model describes the data well
  - χ^2 and p-values calculated

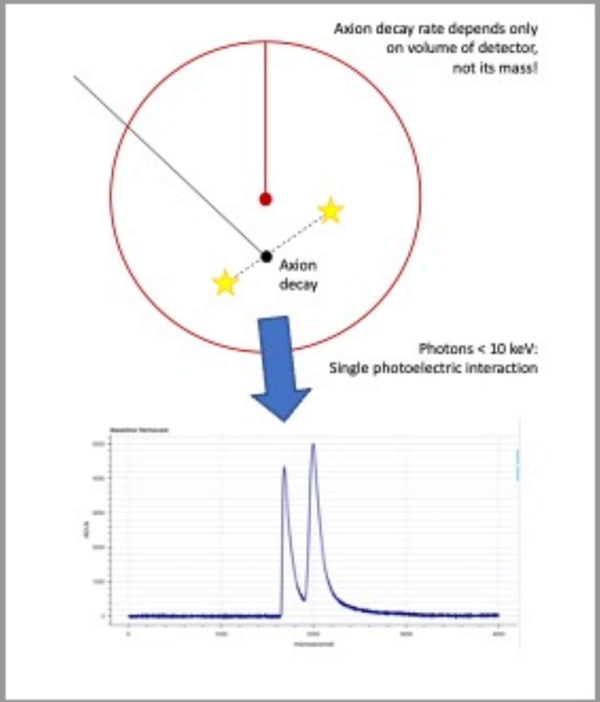


Francisco Vazquez de Sola Fernandez (Queen's)









Paper in internal review stage!

Solar KK Axions

Solar KK axion model predicts accumulation of heavy axions (~10 keV) in the Solar System. These axions decay into two photons of equal mass, absorbed at different locations in an SPC.

Can reject background at 99.99% in the 2-22 keV range by keeping only events with two pulses of similar amplitude, arriving shortly after each other, with risetimes below the values for surface events.

With exposure of 42 days and a detector sensitivity to solar KK axions of ~ 16%, still improve over previous XMASS limits by factor 6.