Detection of low mass WIMPs with Spherical Proportional Counters

George Savvidis
PhD candidate, Queen's University, ON, Canada

On behalf of the NEWS-G collaboration

5th Technology and Instrumentation in Particle Physics conference TIPP2021 (Virtual)

May 25, 2021

Low-Mass Dark Matter detection with NEWS-G

Low-Mass Dark Matter detection with NEWS-G

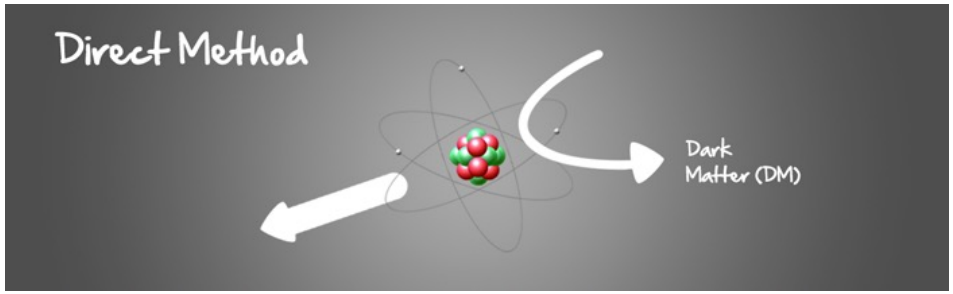
Dark Matter in the Milky Way

WIMPS

Spherical Proportional Counter (SPC)

Direct Detection: WIMP interacts with the gas nuclei through elastic scattering

Measure the recoil energy of the scattered nuclei

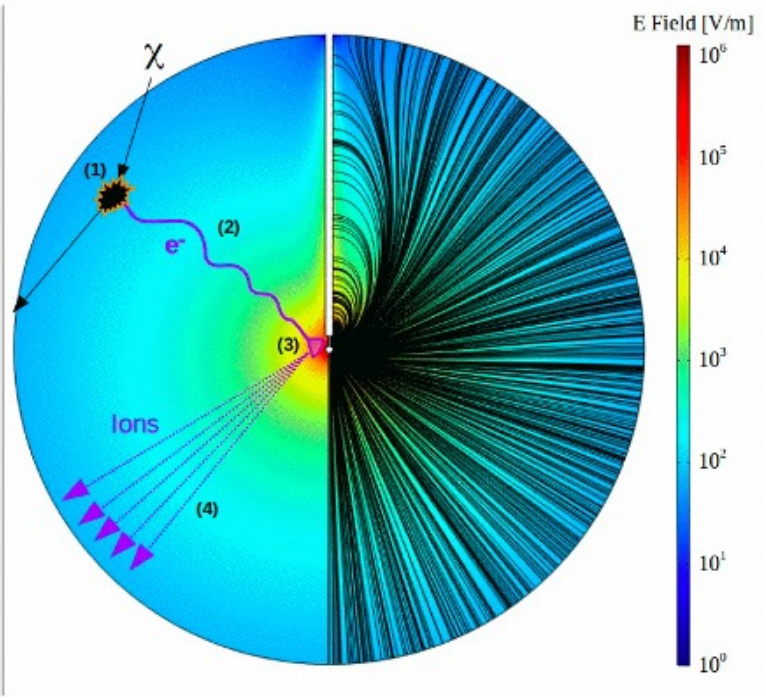


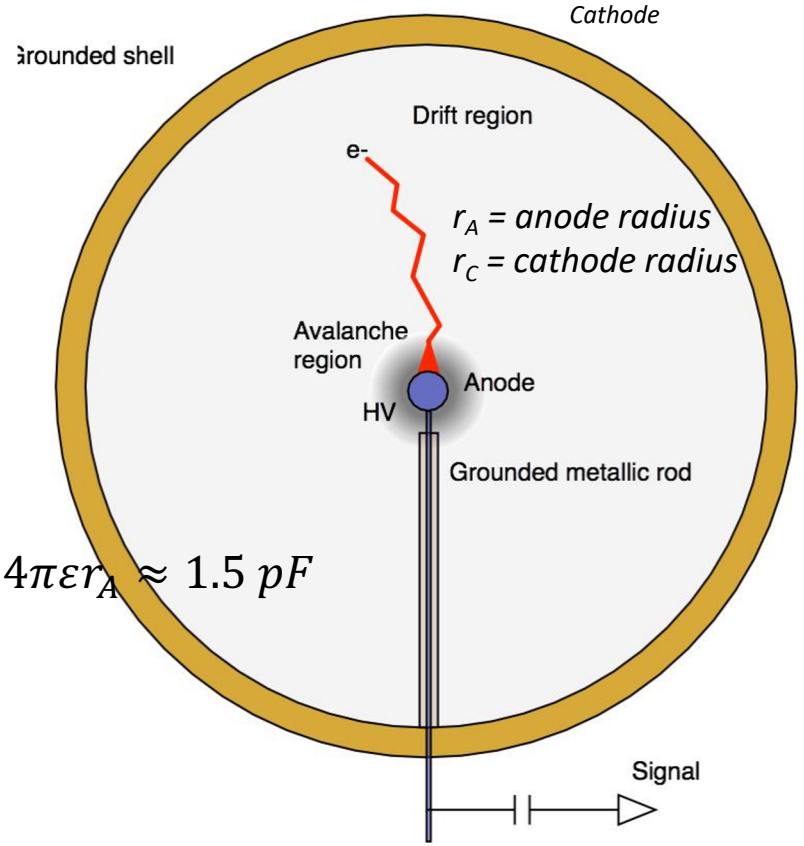
The Spherical Proportional Counter

Spherical Proportional Counter: Principle of Operation

Ideal Spherical Capacitor Field

$$E(r) = \frac{V_0}{r^2}\frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A$$





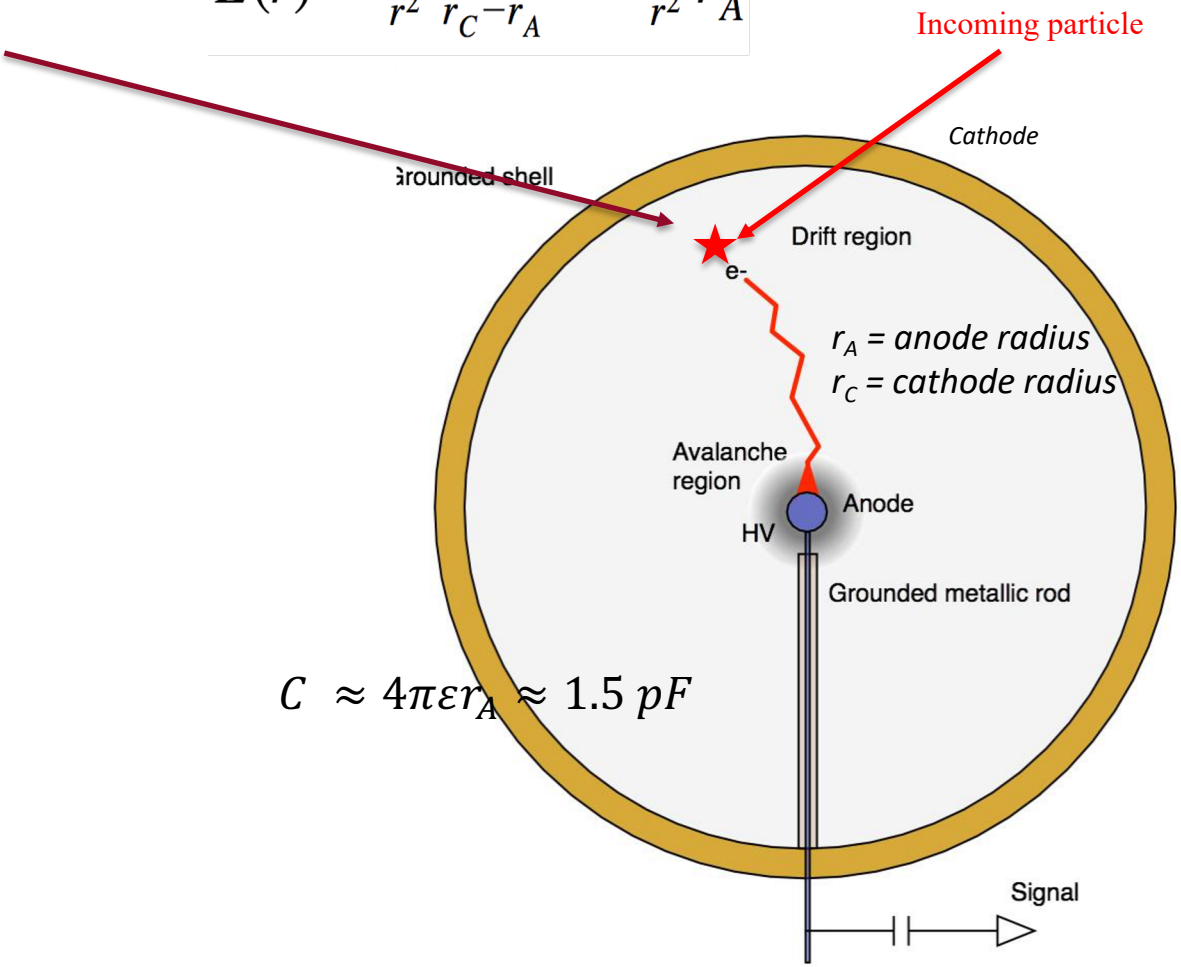
$$C \approx 4\pi\varepsilon r_A \approx 1.5\ pF$$

Spherical Proportional Counter: Principle of Operation

Ideal Spherical Capacitor Field

$$E(r) = \frac{V_0}{r^2}\frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A$$

- Incoming particle ionizes the gas
  - Primary Ionization



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Spherical Proportional Counter: Principle of Operation

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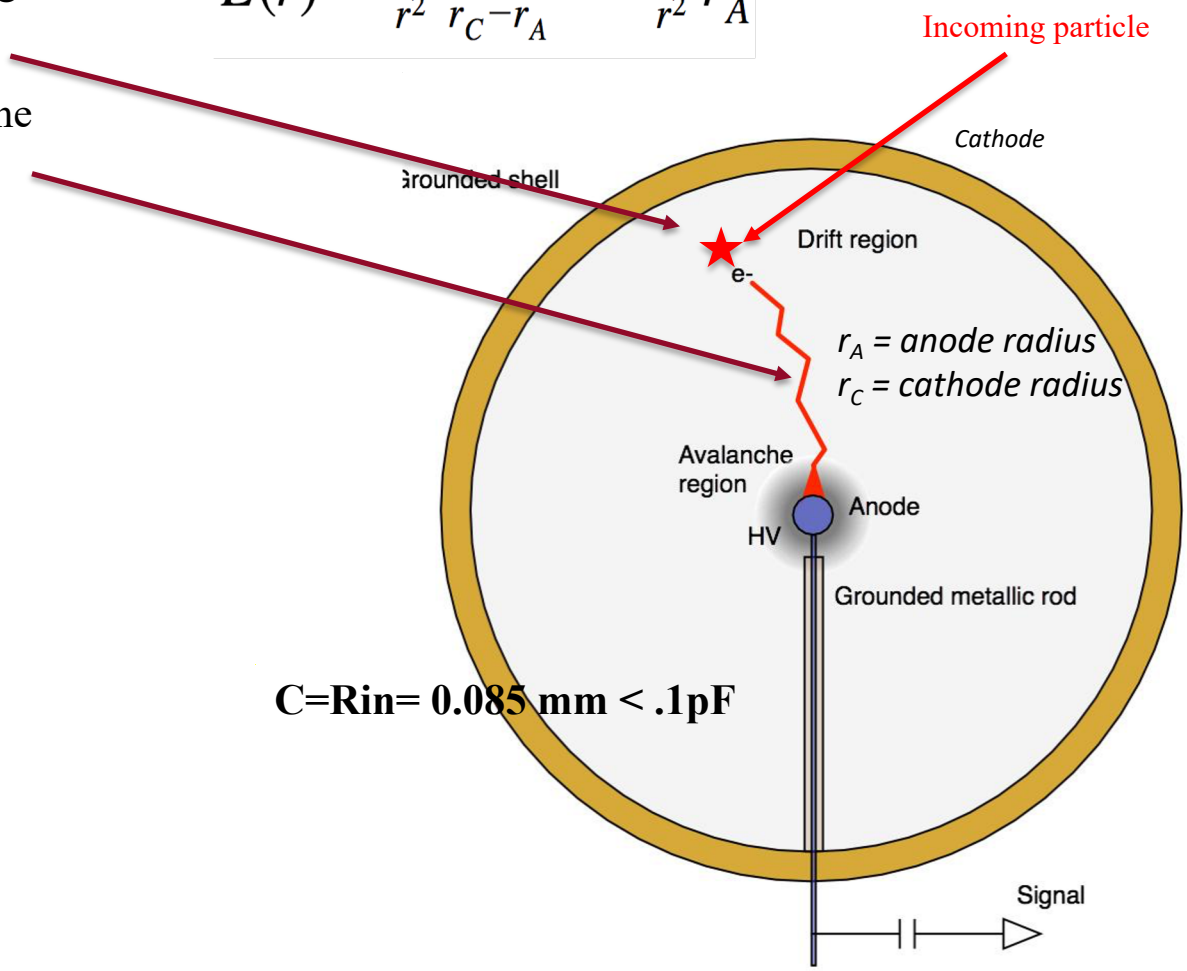
- Incoming particle ionizes the gas
  - Primary Ionization
- e- drift towards the anode at the center along the $\vec{E}$ field lines



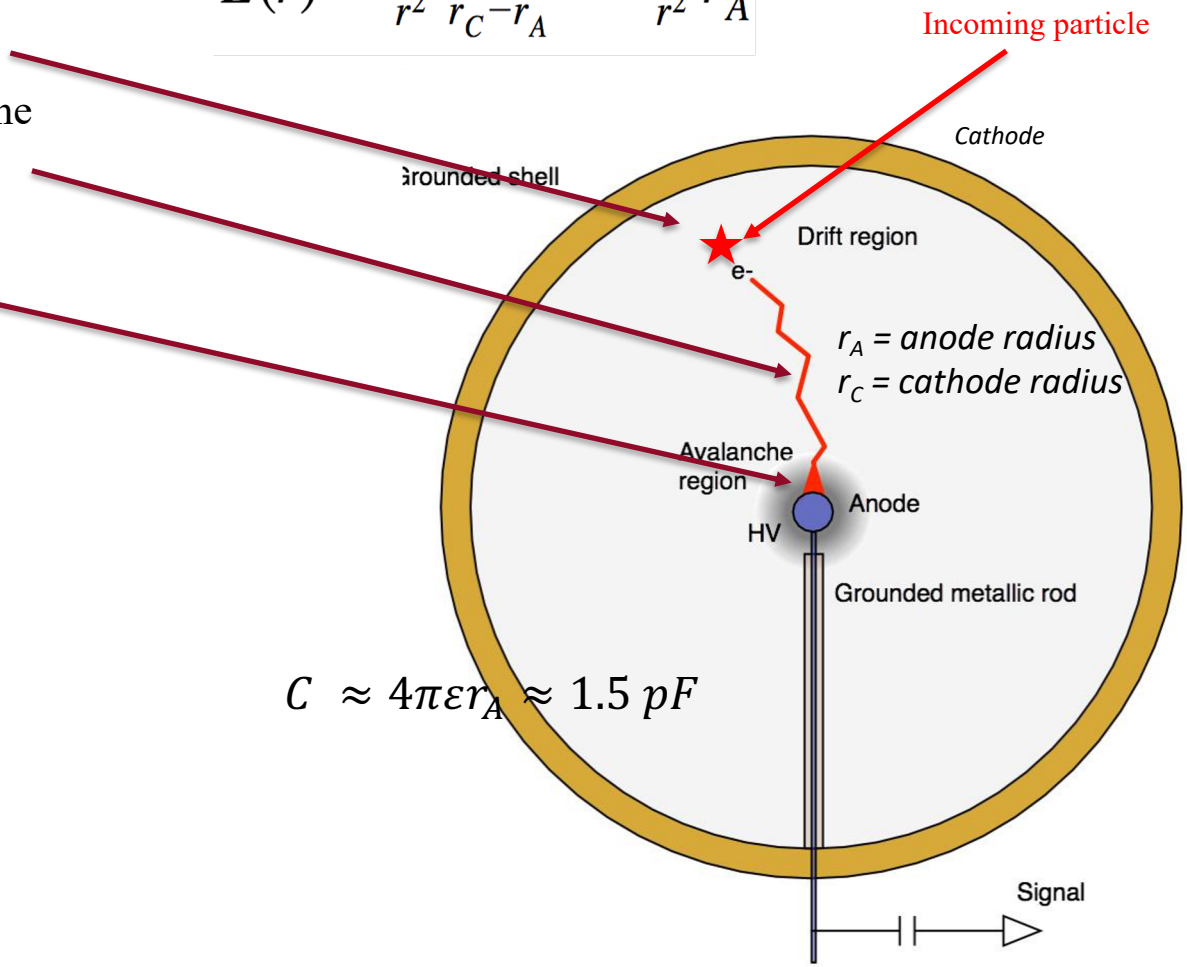
C=Rin= 0.085 mm < .1pF

Spherical Proportional Counter: Principle of Operation

- Incoming particle ionizes the gas
  - Primary Ionization
- e- drift towards the anode at the center along the $\vec{E}$ field lines
- Avalanche occurs
  - Secondary Ionization

Ideal Spherical Capacitor Field

$$E(r) = \frac{V_0}{r^2}\frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A$$



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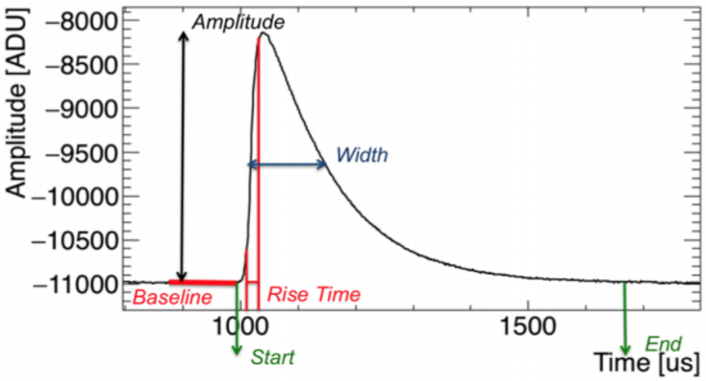
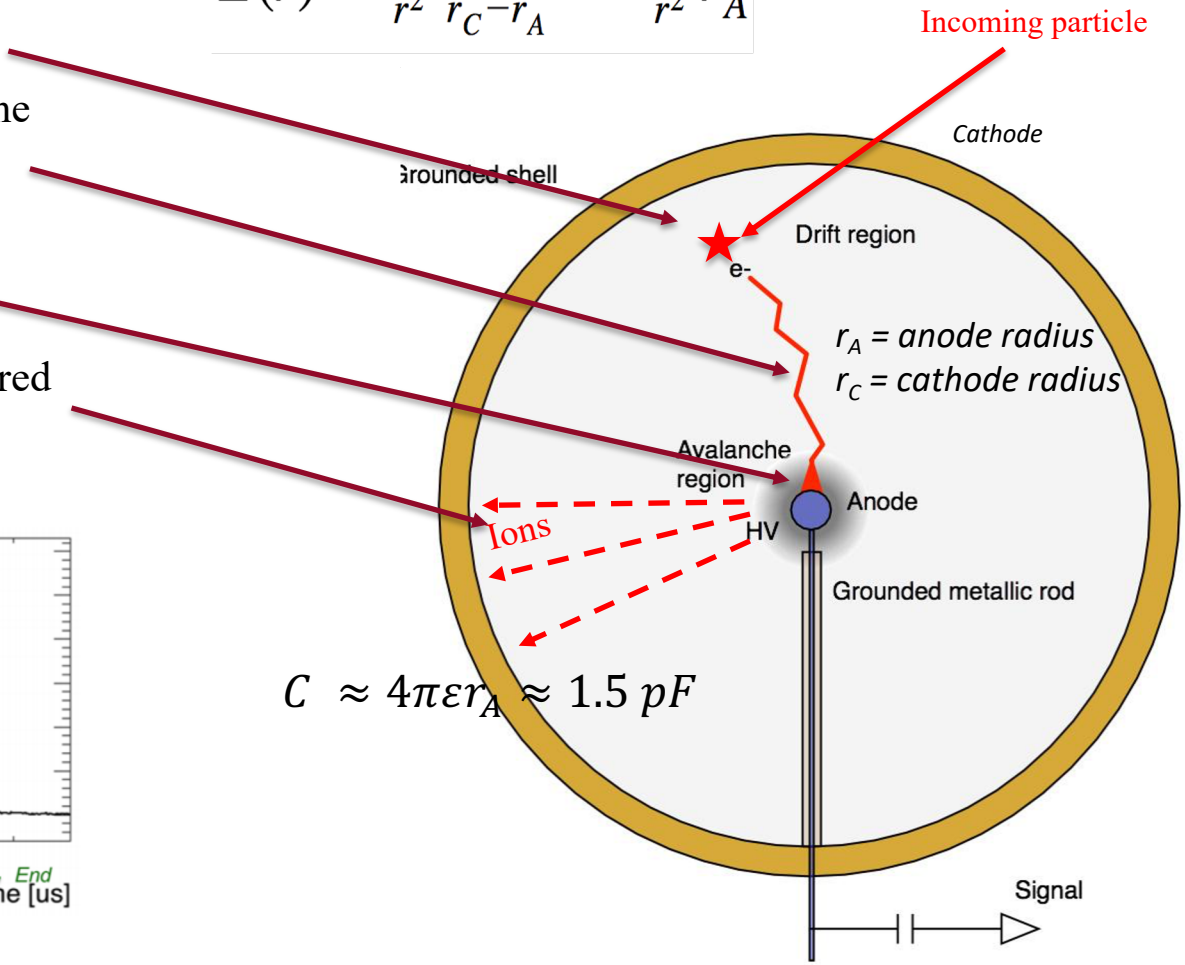
Spherical Proportional Counter: Principle of Operation

Ideal Spherical Capacitor Field

$$E(r) = \frac{V_0}{r^2}\frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A$$

- Incoming particle ionizes the gas
  - Primary Ionization
- e- drift towards the anode at the center along the $\vec{E}$ field lines
- Avalanche occurs
  - Secondary Ionization
- Signal is produced and measured

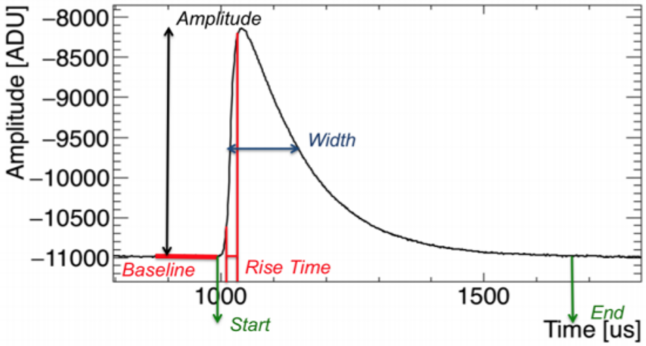




$$C \approx 4\pi\varepsilon r_A \approx 1.5\ pF$$

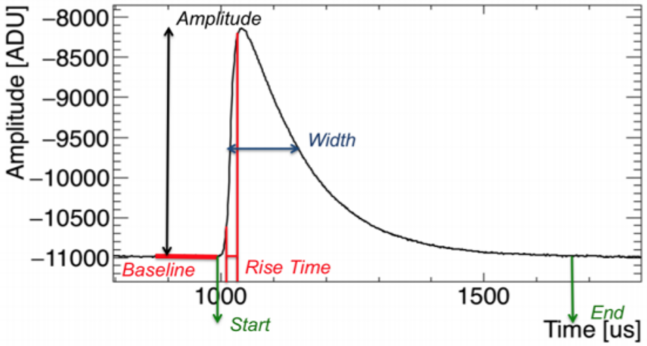
Goal: WIMP detection at SNOLAB!

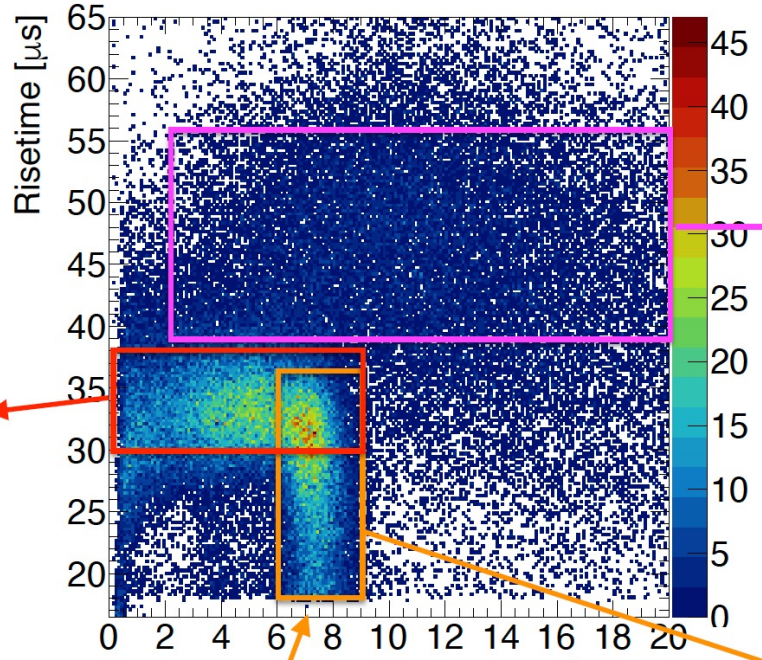
Pulse Shape Discrimination

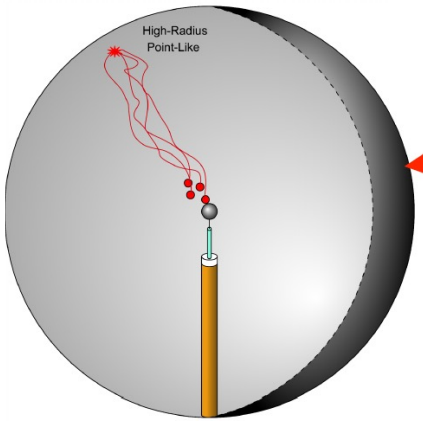


- $Amplitude \propto Particle\ Energy$
- $Risetime \propto Spatial\ Distribution\ of\ Energy\ Deposition$

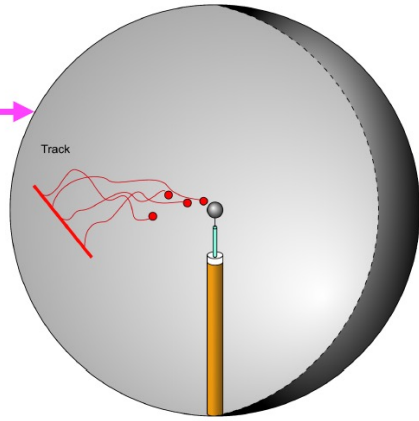
Pulse Shape Discrimination





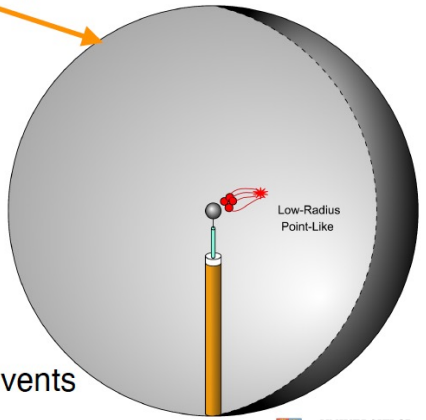


"Surface"-like events



"Muon"-like events

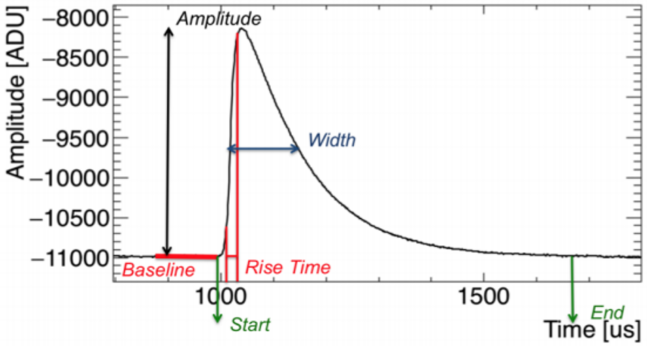
5.9 keV X-rays
from ^{55}Fe decays

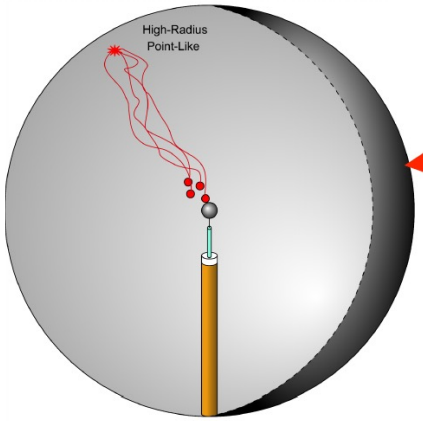


"Signal"-like events

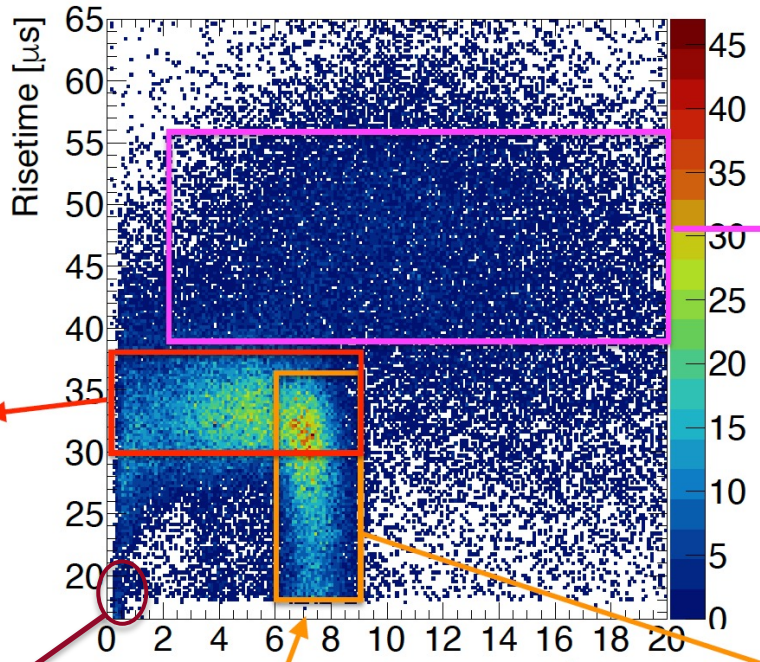
K. Nikolopoulos / 18 March 2021 / NEWS-G: Search for light DM with SPCs

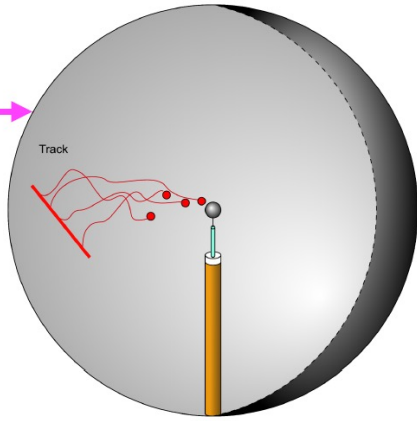
Pulse Shape Discrimination





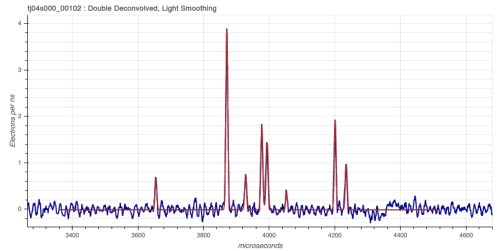
"Surface"-like events





"Muon"-like events

Counting the electrons at very low energies



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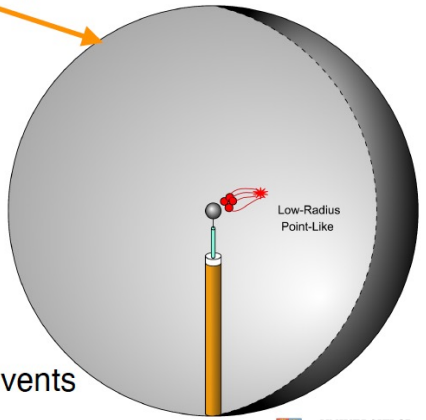


"Signal"-like events

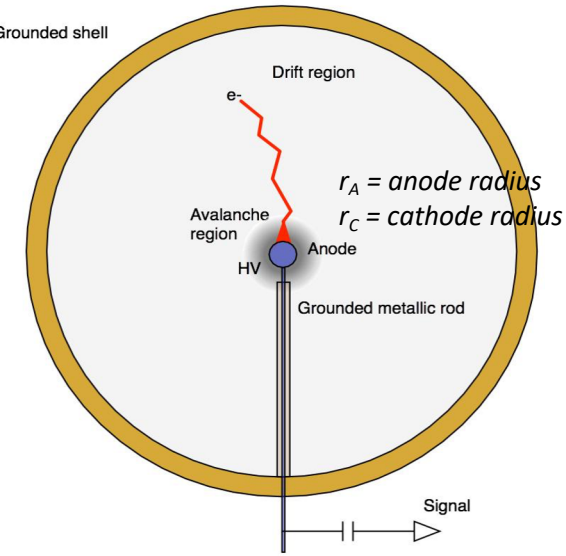
K. Nikolopoulos / 18 March 2021 / NEWS-G: Search for light DM with SPCs

The problem: $\vec{E}$ field vs Gain

Electric Field of an ideal Spherical Capacitor

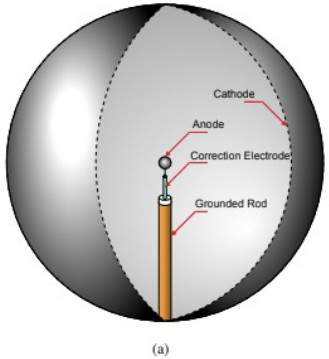
$$E(r) = \frac{V_0}{r^2}\frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A$$

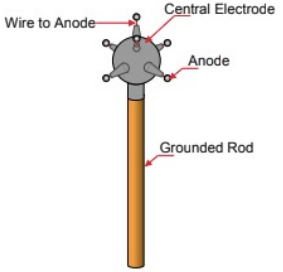
$$Gain \sim \frac{1}{r_A}$$



The solution: Multi-anode sensor

I. Giomataris et al. arXiv:2003.01068

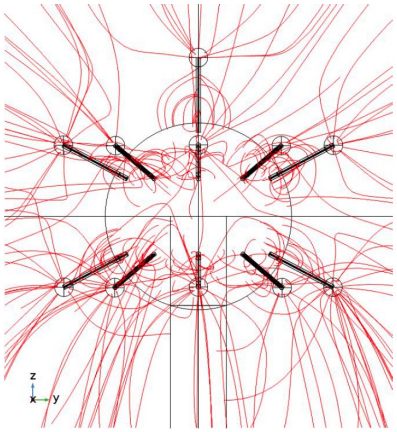


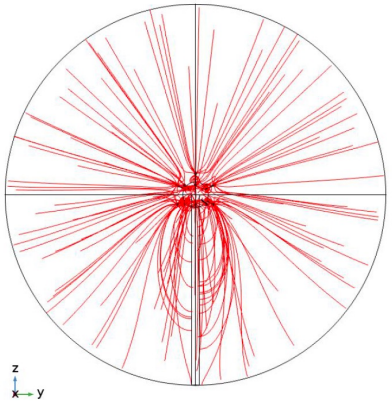


Original achinos paper: https://inspirehep.net/literature/1613557

$$E_{achinos} \approx 11 E_{single}$$

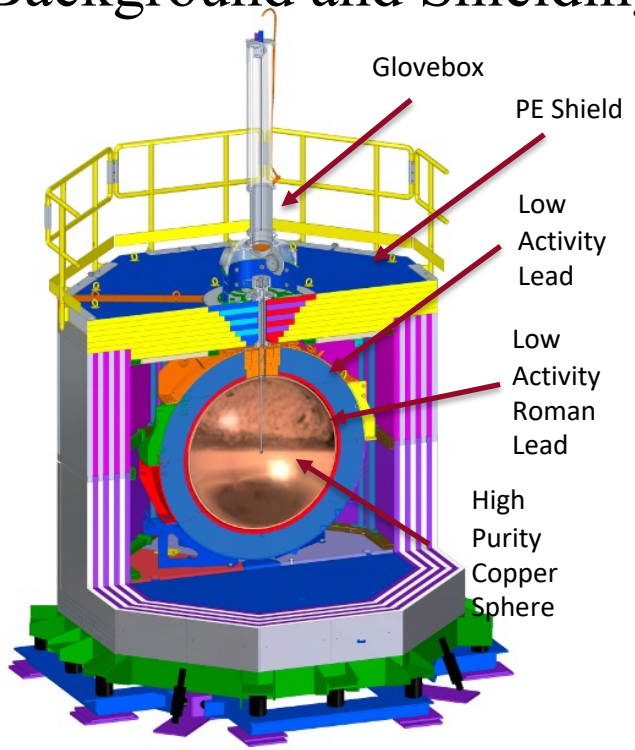
$$Gain \sim \frac{1}{r_A}$$

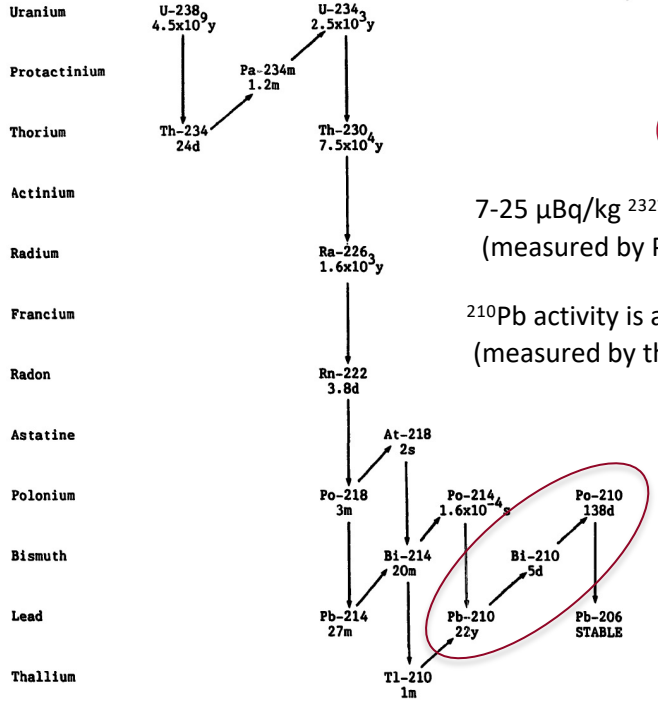




Background

Background and Shielding

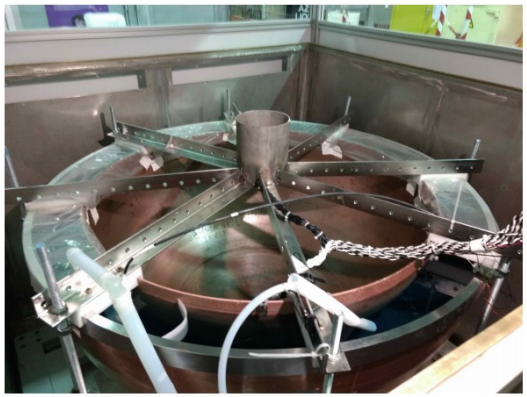




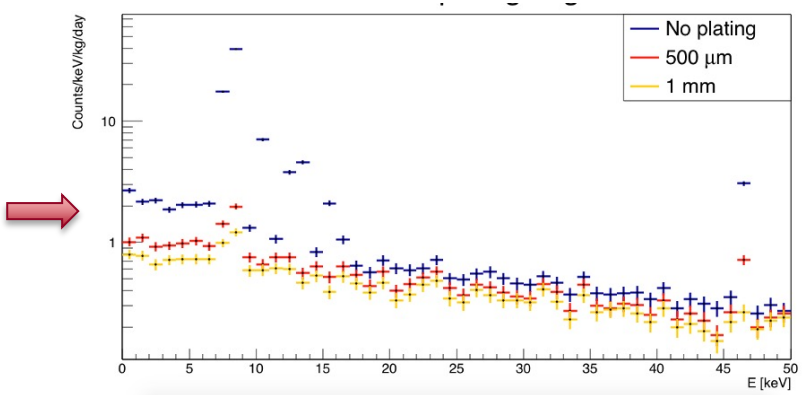
Queen's University

7-25 µBq/kg ^{232}Th / 1-5 µBq/kg ^{238}U
(measured by PNNL using mass spectrometer)

^{210}Pb activity is about 28.5 mBq/kg
(measured by the XMASS collaboration using XIA)



Electroplating at LSM to suppress Pb^{210} background



Balogh, L., Beaufort, C., Brossard, A., Bunker, R., Caron, J. F., Chapellier, M., ... & NEWS-G Collaboration. (2021). Copper electroplating for background suppression in the NEWS-G experiment. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *988*, 164844.

Commissioning results at LSM

Commissioning results at LSM

1 bar Neon+5%CH4

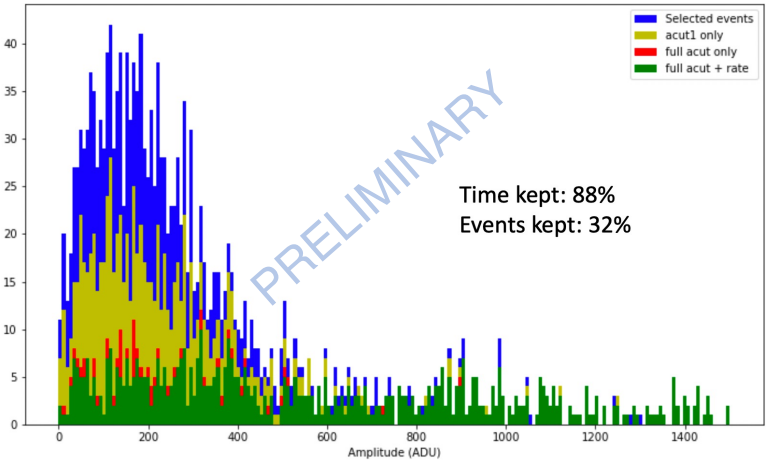
135 mbar **pure** CH4
(Exploitation of proton recoil energies)

Full scale test

- Multi-anode Achinos sensor with 2-readout channels
- Compact Shielding
- Ar37 calibration
- Single Electron calibration with Laser

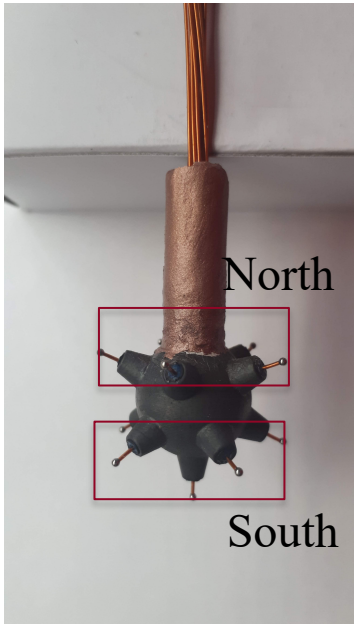
Background reduction with alpha cuts

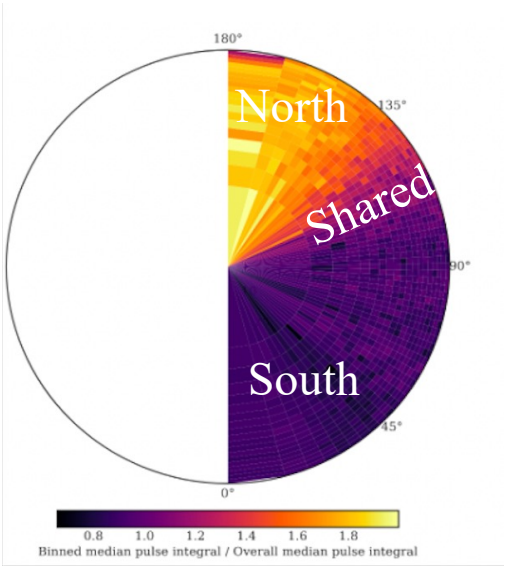
Cut on such high energy events leads to ~70% background events reduction with a 12% exposure reduction



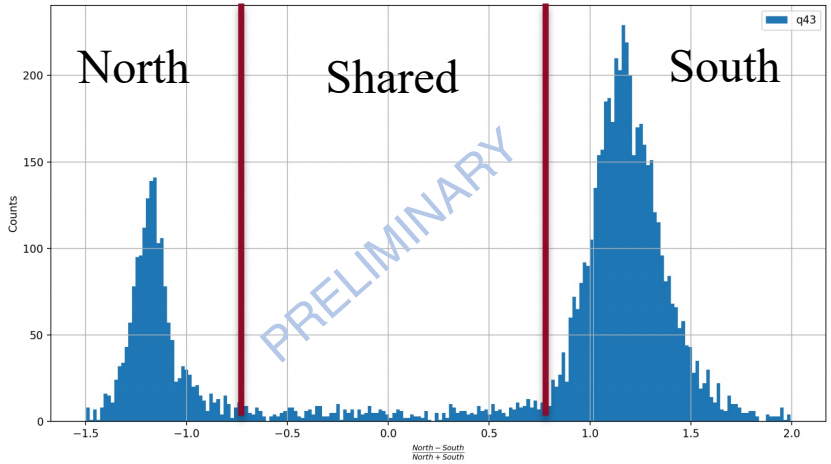
Jean-Marie Coquillat,
M.S.c student,
Queen's Univeristy

Fiducialization study





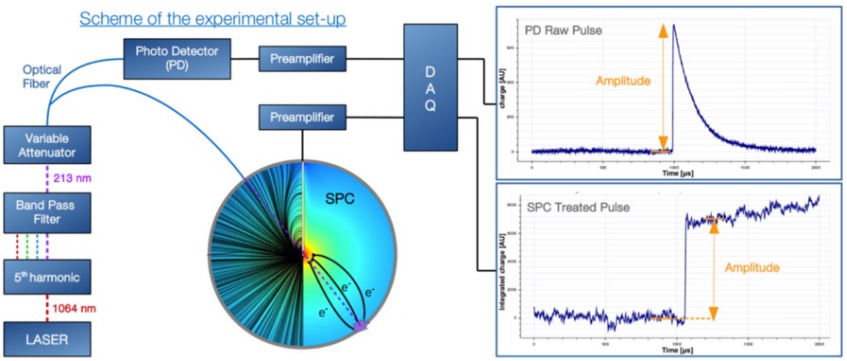
Ar37 Calibration



North events=24%
South events=68%
Shared events=8%

Also see talk by Philippe Gros in the "Gaseous Detector Session"

Single Electron calibration in Pure CH4



Laser:

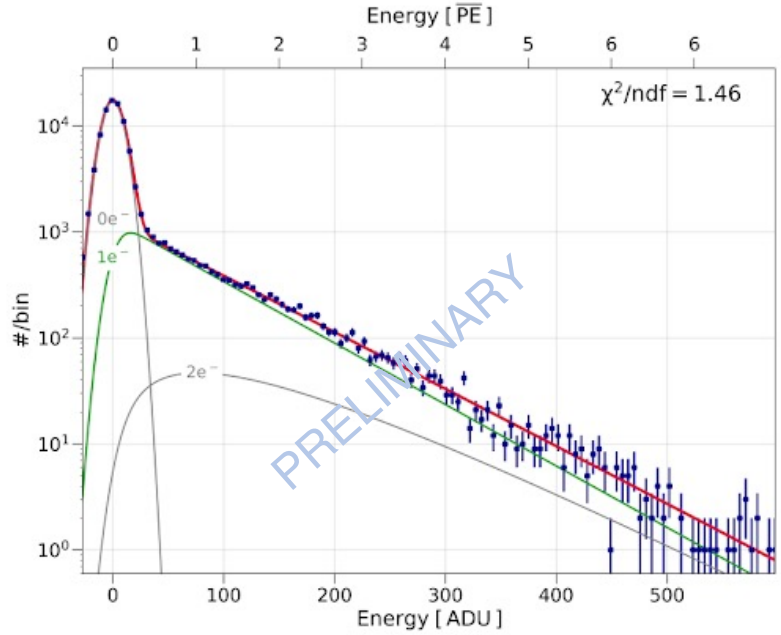
- Measure mean gain to 1% precision
- Measure drift and diffusion time
- Monitor stability of detector within 1%
- Measure trigger threshold efficiency
- Measure of W-value to 1% precision and constraint on the Fano factor

See talk by Philippe Gros in "Gaseous Detector Session"

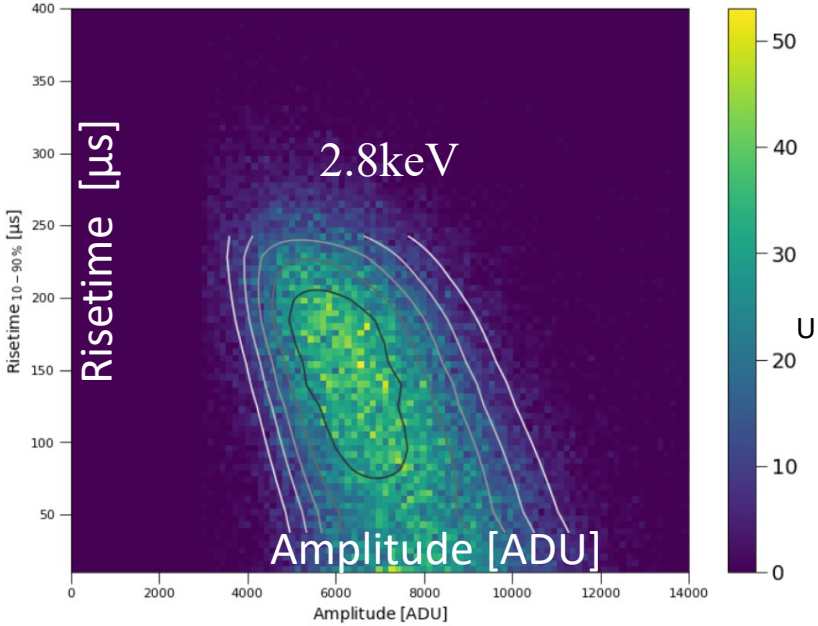
^{37}Ar *decays* 100% *by electron capture to* ^{37}Cl

- K-Shell: 2.8 keV
- L-Shell: 270 eV

Single Electron Calibration



Ar37 Calibration



Daniel Durnford, PhD candidate, University of Alberta

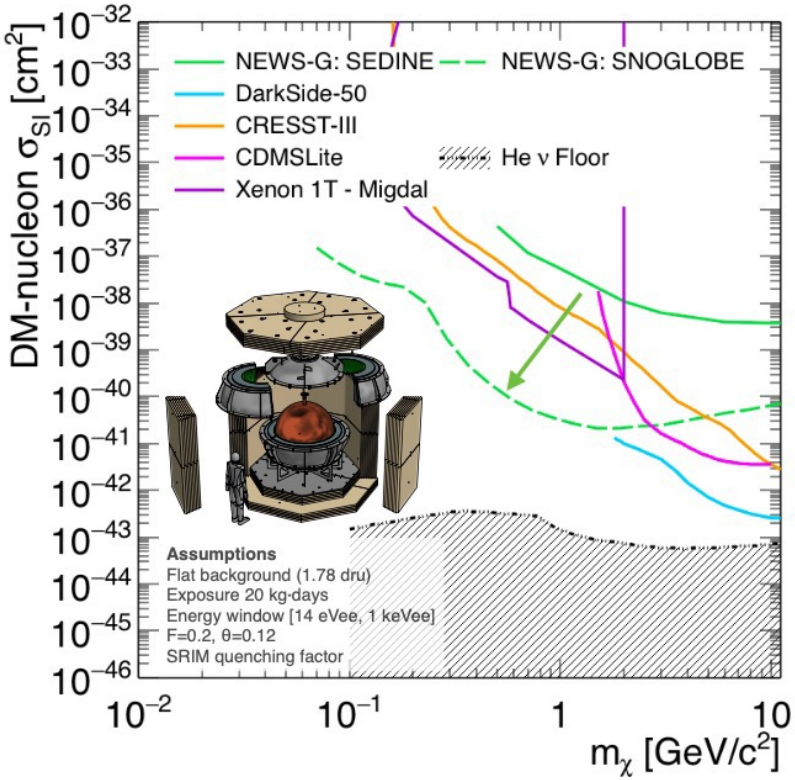
Publication on pure CH4 results soon

The NEWS-G experiment at SNOLAB

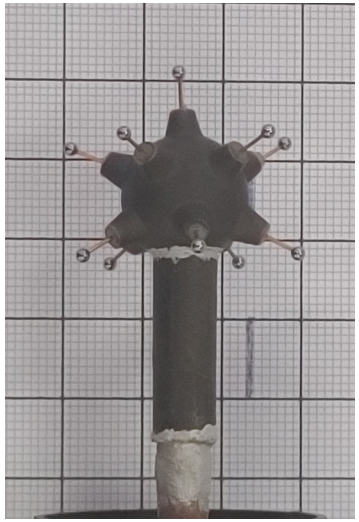
The NEWS-G experiment at SNOLAB

Phases of the Detector Installation at SNOLAB

Projected Sensitivity at SNOLAB



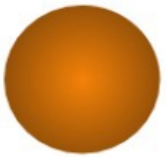
$\emptyset 1.7mm\ Si\ balls$



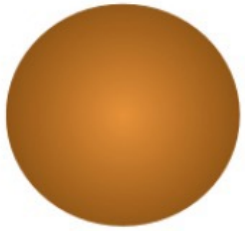
NEWS-G Timeline and Future Projects

SEDINE (LSM)
Ø 60cm
NOSV Cu

SNOGLOBE (SNOLAB)
Ø 130 cm 4
4N Cu



ECUME (SNOLAB)
Ø 130 cm
Electroformed Cu

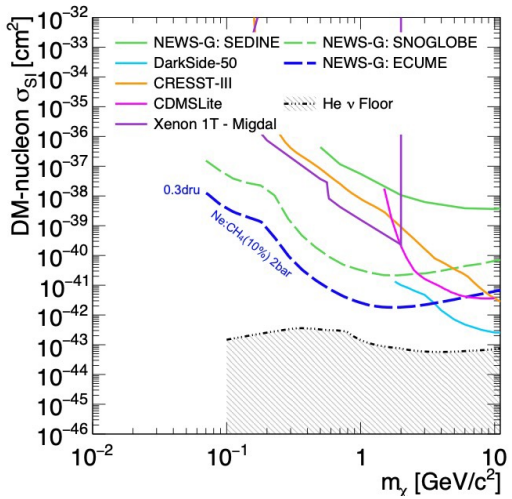


DarkSPHERE
Ø 300 cm
Electroformed Cu

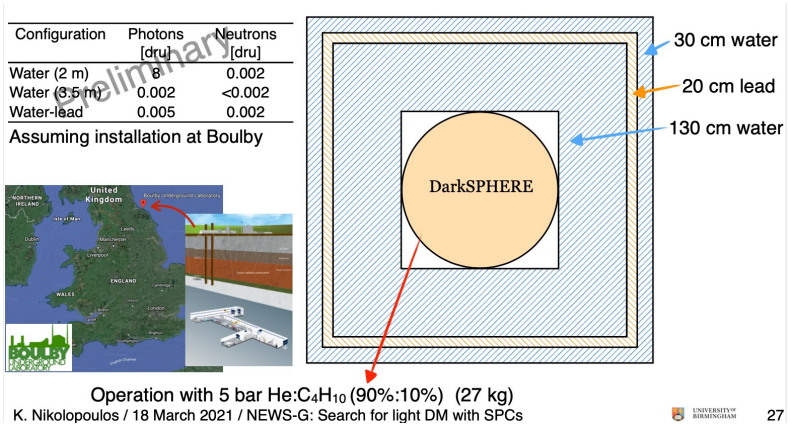
2017	---	2021	2022	2023	2024	2025
First constraints on light dark matter		- SNOGLOBE physics - ECUME construction	ECUME commissioning	ECUME physics	-ECUME physics -DarkSPHERE construction	-ECUME physics -DARKSPHERE installation

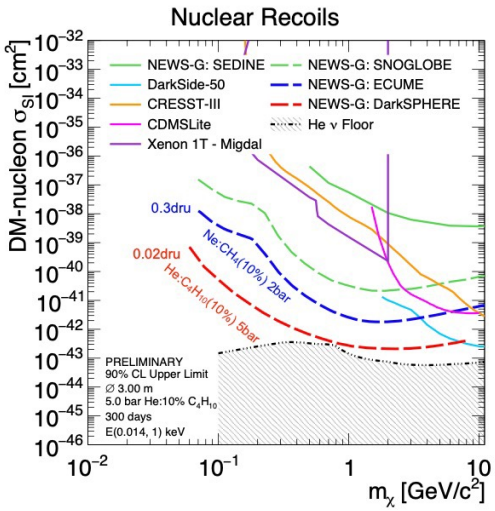
ECuME

ECuME Projected Sensitivity



DarkSPHERE Projected Sensitivity





Thank you for your attention

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

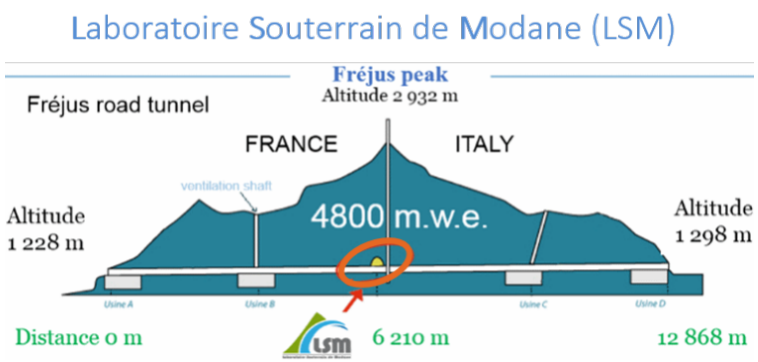
University of Alberta - MC Piro, D Durnford, Y Deng, P O'Brien, C Garrah
- Gas purification, data analysis, simulation

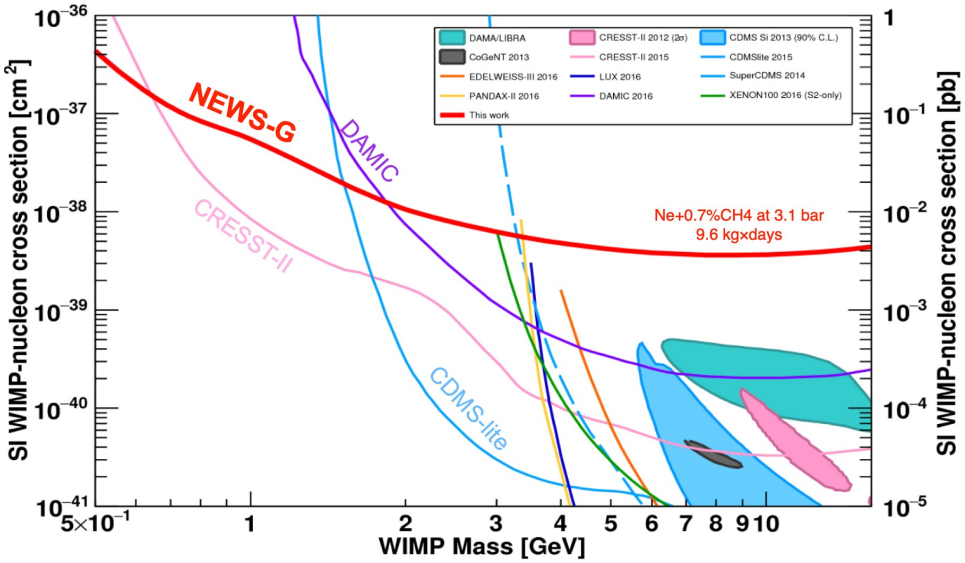
Associated labs: TRIUMF - F Retiere

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

Back up

Results from SEDINE 60cm prototype

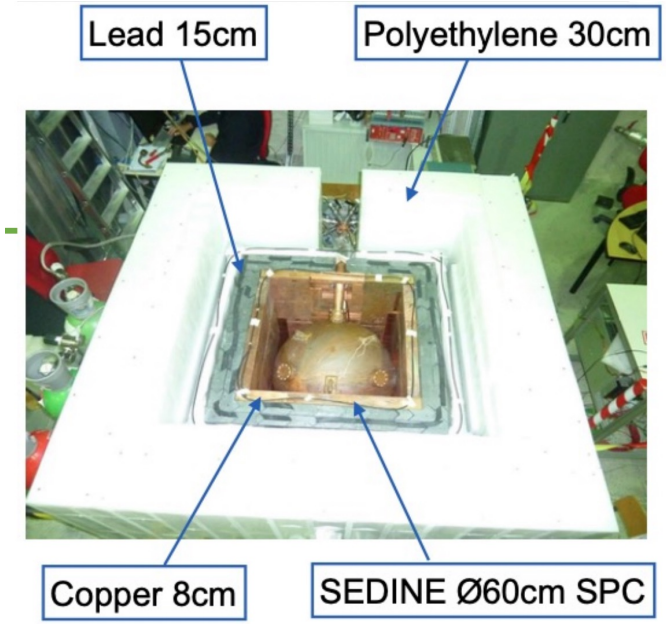




Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018).

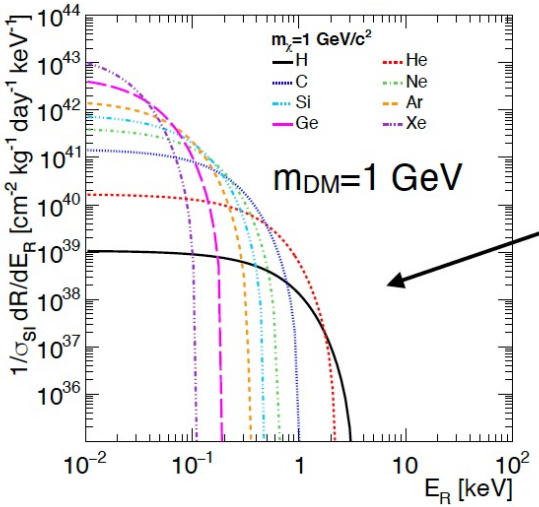
SEDINE: First Prototype

3.1 bars of Ne + 0.7% CH4 42 days of data



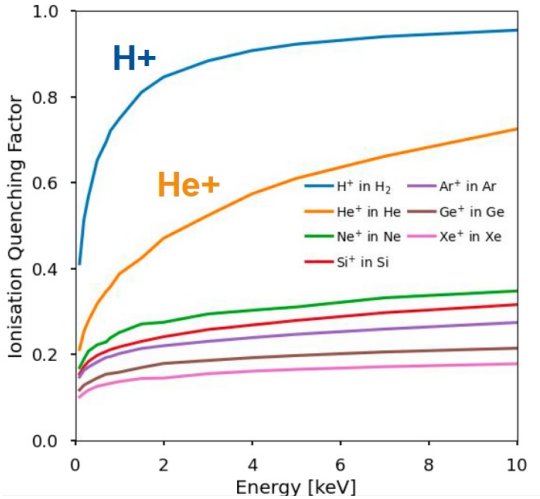
Low-Mass Dark Matter detection with NEWS-G

Light targets: Favourable recoil energies

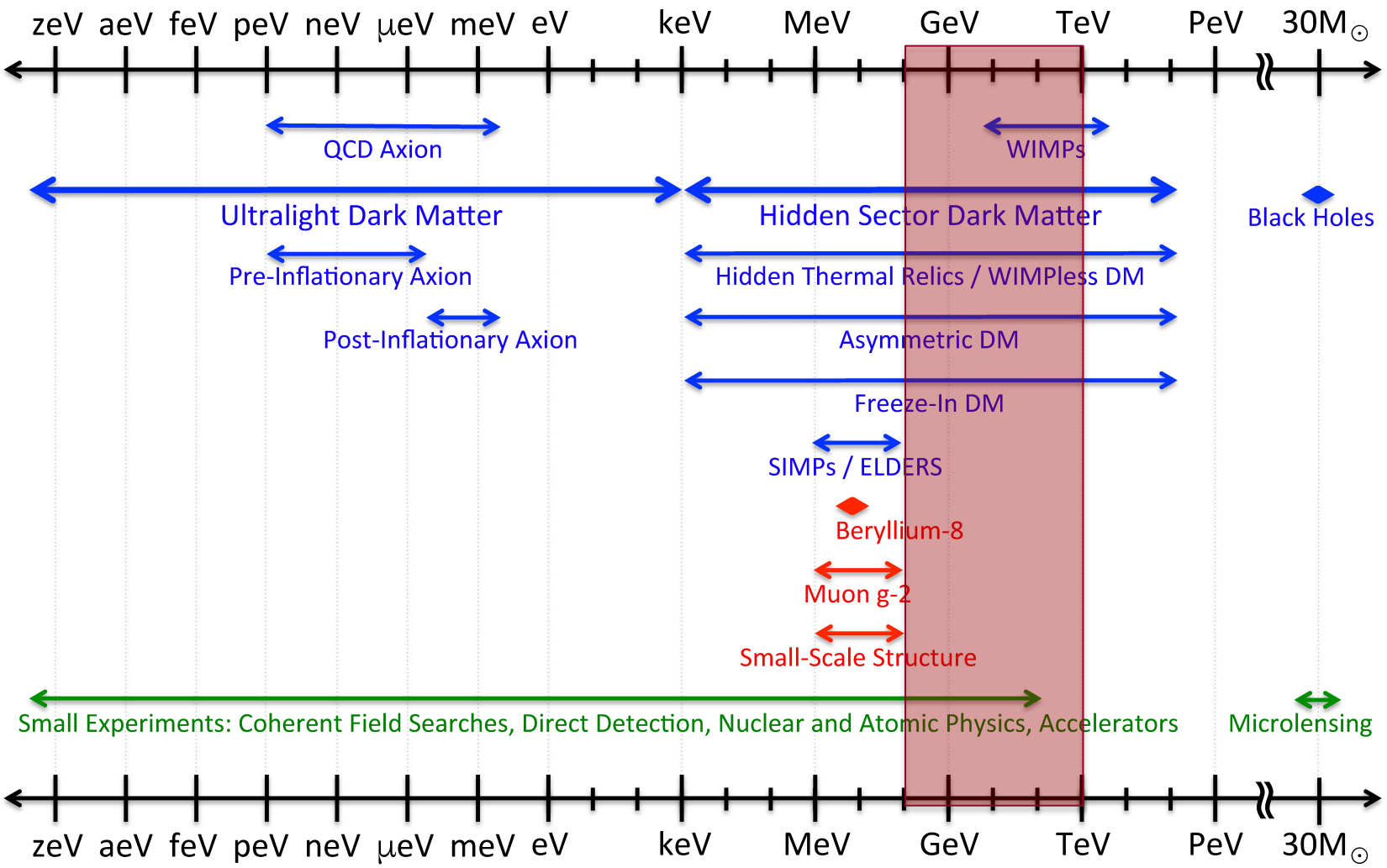


Recoil Energy Distribution

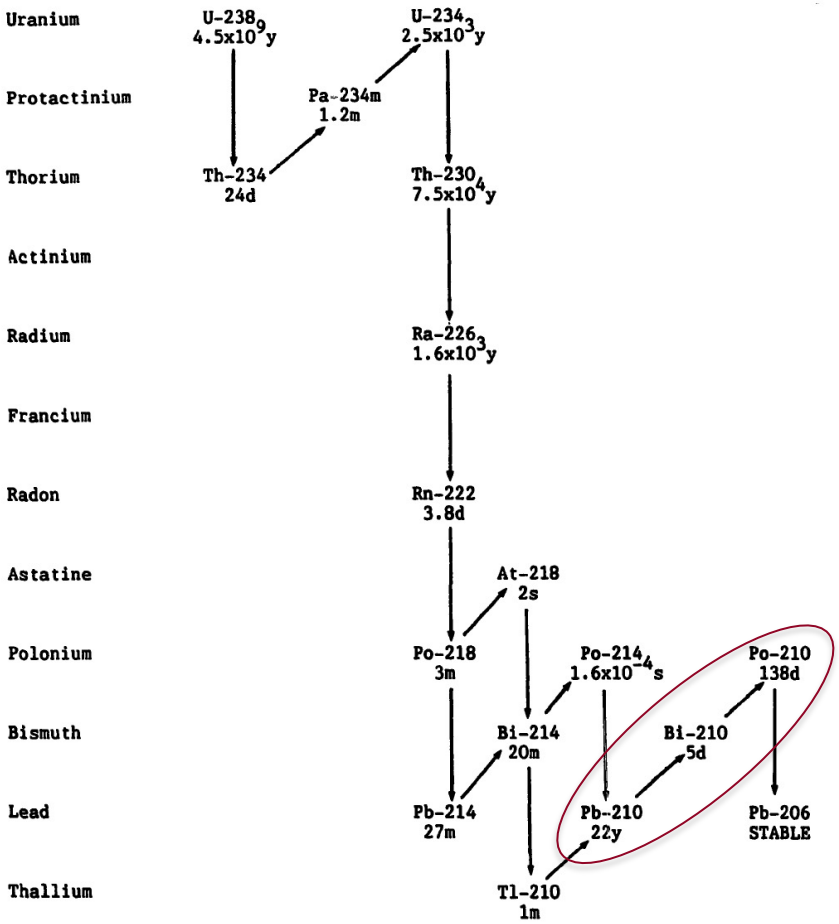
Light targets: Lower Quenching Factor

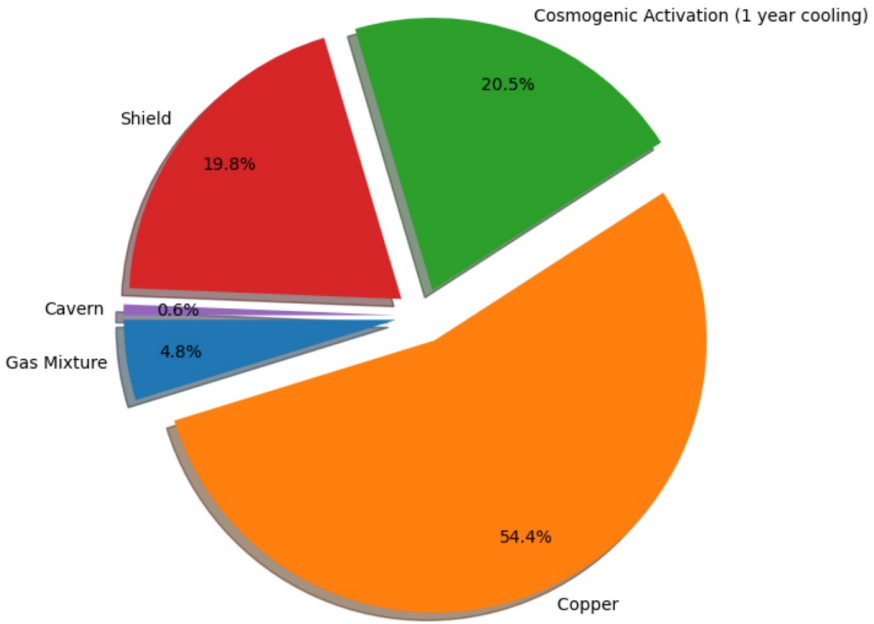


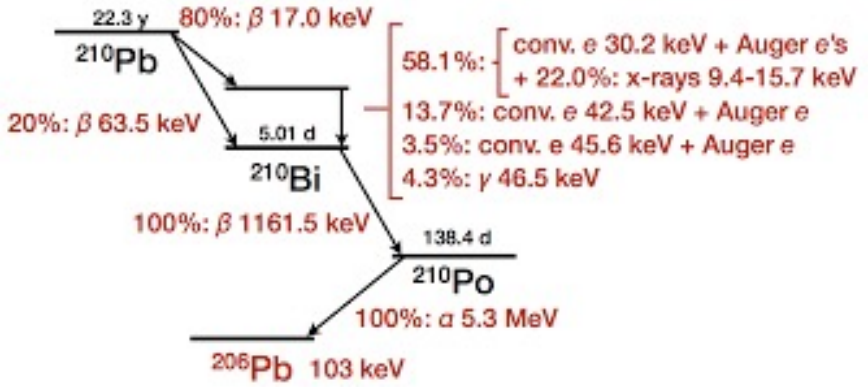
Dark Sector Candidates, Anomalies, and Search Techniques



Background


Uranium
Protactinium
Thorium
Actinium
Radium
Francium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium
U-238 4.5x10^9 y
U-234 2.5x10^3 y
Pa-234m 1.2m
Th-234 24d
Th-230 7.5x10^4 y
Ra-226 1.6x10^3 y
Rn-222 3.8d
At-218 2s
Po-218 3m
Po-214 1.6x10^-4 s
Po-210 138d
Bi-214 20m
Bi-210 5d
Pb-214 27m
Pb-210 22y
Pb-206 STABLE
Tl-210 1m


Cosmogenic Activation (1 year cooling)
Shield
19.8%
20.5%
Cavern
0.6%
Gas Mixture
4.8%
54.4%
Copper


22.3 y
210Pb
80%: β 17.0 keV
20%: β 63.5 keV
5.01 d
210Bi
58.1%: conv. e 30.2 keV + Auger e's
+ 22.0%: x-rays 9.4-15.7 keV
13.7%: conv. e 42.5 keV + Auger e
3.5%: conv. e 45.6 keV + Auger e
4.3%: γ 46.5 keV
100%: β 1161.5 keV
138.4 d
210Po
100%: α 5.3 MeV
206Pb 103 keV